7. Glove Box Filtration

7.1 INTRODUCTION

Glove boxes occupy a middle ground between chemical fume hoods and hot cells as primary containment areas for working with radioactive materials. Glove boxes are Zone I or Zone II spaces for work with materials involving greater risk than would be appropriate for a fume hood but not of sufficient risk to require a hot cell. Zoning is discussed in Sect. 2.2.1. Material appropriate for glove box handling generally presents little or no penetrating radiation hazard. Glove boxes mainly protect against the inhalation of radioactive materials, and glove box filtration plays a significant role in such protection. The escape of radioactive material without sufficient treatment nullifies the protection provided by the glove box. This chapter discusses the filtration of air or other gases associated with the ventilation of these enclosures. To understand the importance of glove box filtration, a clear understanding of the functioning of the glove box itself is necessary.

7.1.1 Description of Glove Boxes

A glove box (Fig. 7.1) is a windowed, airtight enclosure equipped with one or more flexible gloves for manual handling of material inside the enclosure from the outside. Figure 7.2 defines glove boxes and focuses attention on their use in the nuclear industry. Glove boxes are also used in other industries and laboratories to enable the safe handling of pathogenic and toxic materials or to prevent contamination of a material being handled. The main purpose for using a glove box is to permit the use of the hands in manipulating hazardous materials through a membrane (the glove) while preventing release of the material to the environment.

There is no commercial standard to cover the construction of glove boxes. As a result, many

PHOTO 88277A

EXHAUST MANIFOLD

FLEXIBLE DUCT (DOWNSTREAM FROM EXHAUST HEPA FILTER)

SERVICE LINES

LIGHTING FIXTURE

WINDOW

"H" CROSS SECTION WINDOW GASKET

BAG-OUT PORT

GLOVE AND GLOVEPORT

PRESSURE GAGE
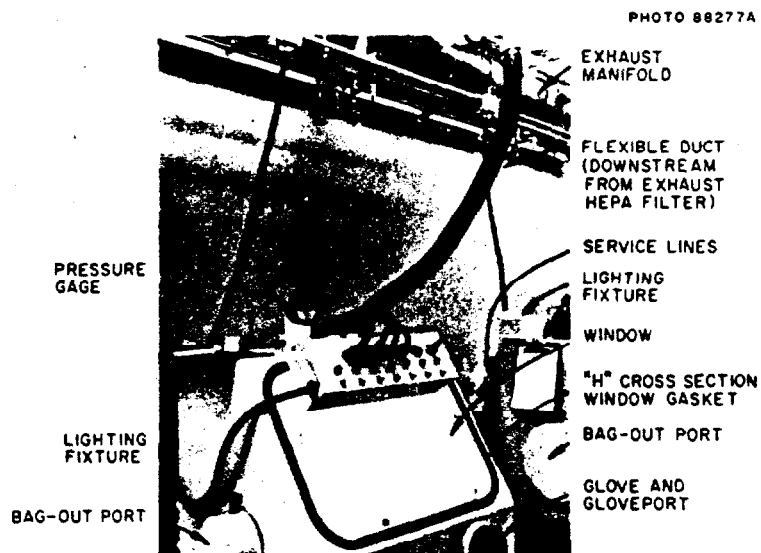
LIGHTING FIXTURE

BAG-OUT PORT

Fig. 7.1. Typical glove box showing major features. Box is mounted on wheels. All services are brought into back of box. Note differences in lighting fixtures and bag-out ports of two boxes that can be seen. Flexible duct is permissible only downstream of the glove box exhaust HEPA filter, mounted on the back of the box.

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GLOVE BOX

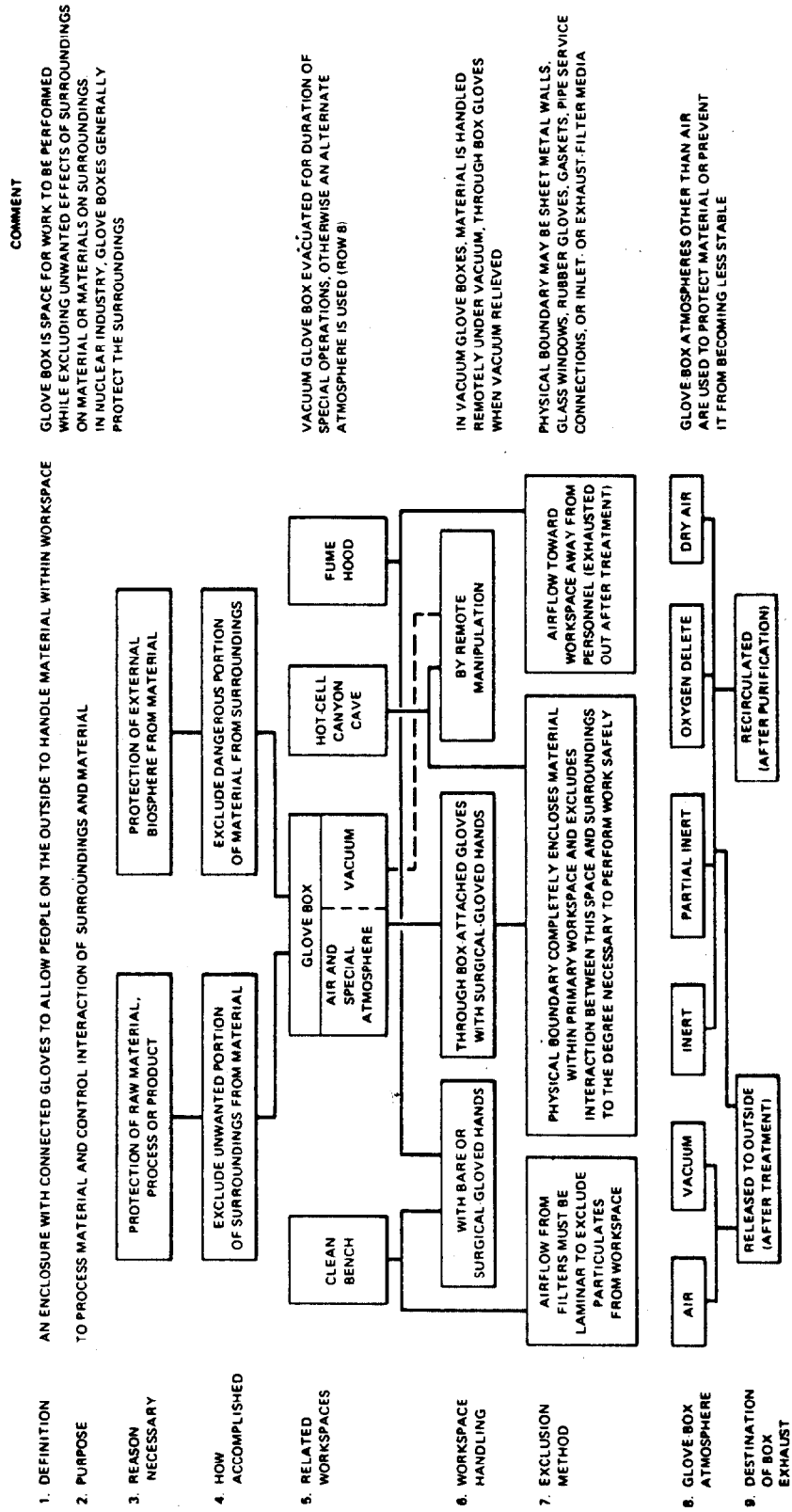**COMMENT**

1. DEFINITION — AN ENCLOSURE WITH CONNECTED GLOVES TO ALLOW PEOPLE ON THE OUTSIDE TO HANDLE MATERIAL WITHIN WORKSPACE — GLOVE BOX IS SPACE FOR WORK TO BE PERFORMED WHILE EXCLUDING UNWANTED EFFECTS OF SURROUNDINGS ON MATERIAL OR MATERIALS ON SURROUNDINGS

2. PURPOSE — TO PROCESS MATERIAL AND CONTROL INTERACTION OF SURROUNDINGS AND MATERIAL — IN NUCLEAR INDUSTRY, GLOVE BOXES GENERALLY PROTECT THE SURROUNDINGS

PROTECTION OF EXTERNAL BIOSPHERE FROM MATERIAL
PROTECTION OF RAW MATERIAL, PROCESS OR PRODUCT

3. REASON NECESSARY

EXCLUDE DANGEROUS PORTION OF MATERIAL FROM SURROUNDINGS
EXCLUDE UNWANTED PORTION OF SURROUNDINGS FROM MATERIAL

4. HOW ACCOMPLISHED

5. RELATED WORKSPACES — CLEAN BENCH — GLOVE BOX — FUME HOOD — HOT-CELL CANYON CAVE — VACUUM GLOVE BOX EVACUATED FOR DURATION OF SPECIAL OPERATIONS, OTHERWISE AN ALTERNATE ATMOSPHERE IS USED (ROW 8)

AIR AND SPECIAL ATMOSPHERE / VACUUM

6. WORKSPACE HANDLING — WITH BARE OR SURGICAL-GLOVED HANDS — THROUGH BOX-ATTACHED GLOVES WITH SURGICAL-GLOVED HANDS — BY REMOTE MANIPULATION — IN VACUUM GLOVE BOXES, MATERIAL IS HANDLED REMOTELY UNDER VACUUM, THROUGH BOX GLOVES WHEN VACUUM RELIEVED

7. EXCLUSION METHOD — AIRFLOW FROM FILTERS MUST BE LAMINAR TO EXCLUDE PARTICULATES FROM WORKSPACE — PHYSICAL BOUNDARY COMPLETELY ENCLOSES MATERIAL WITHIN PRIMARY WORKSPACE AND EXCLUDES INTERACTION BETWEEN THIS SPACE AND SURROUNDINGS TO THE DEGREE NECESSARY TO PERFORM WORK SAFELY — AIRFLOW TOWARD WORKSPACE AWAY FROM PERSONNEL (EXHAUSTED OUT AFTER TREATMENT) — PHYSICAL BOUNDARY MAY BE SHEET METAL WALLS, GLASS WINDOWS, RUBBER GLOVES, GASKETS, PIPE SERVICE CONNECTIONS, OR INLET- OR EXHAUST-FILTER MEDIA

8. GLOVE BOX ATMOSPHERE — AIR — VACUUM — INERT — PARTIAL INERT — OXYGEN DELETE — DRY AIR — GLOVE-BOX ATMOSPHERES OTHER THAN AIR ARE USED TO PROTECT MATERIAL OR PREVENT IT FROM BECOMING LESS STABLE

9. DESTINATION OF BOX EXHAUST — RELEASED TO OUTSIDE (AFTER TREATMENT) — RECIRCULATED (AFTER PURIFICATION)

Fig. 7.2. Characteristics of glove boxes.

different designs exist. Fabricators in the United States build and sell glove boxes and related equipment either of their own design or to customer specifications. Few parts of such boxes are interchangeable. Even though some standardization has resulted from recurring requirements of single users, few features of glove box design are universally accepted in the nuclear industry. Clear evidence of the differences in need and opinion on this subject is given in *Glove Boxes and Containment Enclosures*,[1] in which considerable design and operational data were documented in 1962.

Most glove boxes contain no special radiation shielding. Their volume varies from 20 to 100 ft³, with geometry that makes them little wider than an outstretched arm. They contain one or more safety-glass, laminated-glass, or plastic viewing windows on at least one side, with glove ports, usually in multiples of two, at various locations in the walls. Interior workspace is reserved for primary operating purposes on the box floor between the glove ports and within reach of a gloved hand and arm. Remote handling capability, other than tool extensions for the gloved hand, is usually not provided. Glove boxes are normally kept at a negative pressure of 0.3 to 1.0 in.wg relative to their surroundings. The maximum safe differential pressure between the interior and exterior of the box is usually less than 10 in.wg; greater differential pressure may damage or rupture a glove or window, with subsequent loss of box integrity. Material transfers between the box interior and exterior, commonly made through a bag-out port, are time-consuming and tedious. The associated HEPA filter installation must adapt to these limitations and still provide reliable service. Hybrid glove box–shielded cells, vacuum glove boxes, room-high glove boxes, glove box "trains," etc., are often encountered, and all require reliable filter installations.

Special atmospheres, such as inert gas and dry air, are often used in glove boxes to enhance safety or to provide a necessary processing environment within the box. *Inert Atmospheres*,[2] by White and Smith, provides design information on special atmosphere boxes. This chapter is mainly concerned with air-ventilated boxes, since their application is more general and the principles can be applied, with only slight modification, to other atmospheres.

7.1.2 Importance of Glove Box Ventilation and Filtration

Operations conducted in glove boxes often provide the elements for unstable conditions (e.g., fire and pressurization). A properly designed and operated glove box ventilation system minimizes these instabilities and the possibility of an accidental release of airborne radioactive material. Air is a safe glove box atmosphere for most operations. On the other hand, operations on pyrophoric materials such as plutonium, or the presence of reactive gases such as hydrogen, may require a special atmosphere (e.g., low oxygen, inert gas, vacuum).

For air-atmosphere boxes, ventilation at relatively low flow rates provides sufficient dilution of the limited combustible volatiles found in well-operated glove boxes. The correct airflow quantity and pattern, along with the proper location of supply and exhaust connections, minimizes the likelihood of fire while providing sufficient dilution to prevent the buildup of explosive gases (Sect. 7.2.1). Air circulation also removes some of the equipment heat generated inside the box and helps maintain reasonable working temperatures for the operator (Sect. 7.2.2). However, this convective cooling may not be sufficient to remove all the process heat generated in the box, and auxiliary cooling may be required. A well-designed glove box ventilation system includes vacuum- and pressure-surge relief (Sect. 7.2.6) and adequate pressure control to maintain proper pressure differentials between the glove box and its surroundings (Sect. 7.2.5). If a glove should tear or accidentally come off, there should be an assured flow of air through the opening into the box, sufficient to prevent outleakage of contamination until the port is closed (Sect. 7.2.4). Instruments to give foreknowledge of imminent filter plugging and the ability to change filters without undue delay or effort are necessities of a well-designed and -operated glove box installation. In short, the glove box ventilation and filtration system must be capable of reliable performance to assure the glove box technician that he may safely operate the box without fear of airborne contamination to himself, his neighbors, and the environment.

7.2 DESIGN OF GLOVE BOX VENTILATION SYSTEMS

The air exchange rate is an important consideration in all glove boxes. In large boxes (>100 ft³), distribution and correct internal flow patterns are also important. Spaces likely to be poorly ventilated (e.g., centrifuge wells) must be given special consideration to avoid stagnant pockets.

For normal operations, flow rate is based on dilution of evolved combustible or corrosive gases and heat dissipation, and is often based on prior

experience. Exhaust capability must be sufficient to provide safety under postulated abnormal conditions, including the loss of a glove.

Operating personnel, industrial hygienists, and radiation specialists can assist the designer in establishing realistic requirements, particularly when an existing system is being replaced or revised. The types and quantities of materials to be used inside the box and their toxicity and state (wet slurry, dry powder, etc.) must be considered when establishing the air exchange rate and velocity. When exposed radioactive material is handled inside a glove box, the box becomes the primary containment. Therefore, the glove box should under no circumstances be at a positive pressure relative to its surroundings. A pressurized glove box provides a motive force for airborne contamination to leak from the box into the workroom. Negative pressure inside the box is essential when working with radioactive material.

7.2.1 Dilution of Evolved Gases

A high air exchange rate is often required to dilute fumes generated in an air-ventilated glove box. When evolved gases, vapors, and particles are not flammable, toxic, or corrosive, flow rates just sufficient to maintain a negative pressure, with differentials from 0.3 to 1.0 in.wg in the box, may be employed. However, when fumes or vapors are hazardous, a higher ventilation rate is necessary. The maximum generation rate of hazardous substances must be determined to establish the minimum airflow rates needed for dilution. The following equations can be used to determine minimum safe airflow rates.[3]

$$Q = \frac{R \ (10^6)(S)}{L} \ ,$$ (7.1)

where

Q = required dilution flow rate, cfm;

R = contaminant generation rate, cfm;

S = safety factor (4 to 10 suggested, depending on volatility, flash-point temperature, degree of mixing, and risk);

L = limit value of contaminant, volume parts per million (vpm) [use threshold limit value (TLV) for toxic vapors and lower explosive limit (LEL),[4] converted to vpm, for combustible vapors].

If the contaminant vapor is evaporated from a liquid, the contaminant generation rate, R, can be determined using the rate of liquid evaporated.

$$R = \frac{W}{M} \ (359) \ \frac{t + 460}{492}$$ (7.2)

where

W = liquid evaporation rate, lb of solvent per minute;

M = molecular weight of contaminant;

t = air temperature, °F.

Equation (7.2) assumes that a pound mole of gas will occupy 359 ft³ at 32°F and standard pressure. The dilution flow rate, Q, in Eq. (7.1) assumes that the dilution air is free of the contaminant under consideration; otherwise the background concentration of the contaminant in the dilution air (in vpm) must be subtracted from the limit value, L, in the denominator.

Concentration gradients can easily be formed during rapid vaporization if the hazardous gas is much lighter or heavier than air and there is poor mixing;[5] safety factors above 7 should be used in such cases. For example, 1 lb of acetone evaporated in a box in 1 hr requires a dilution rate of 5.1 cfm times the safety factor, S, for assurance of dilution below the lower explosive limit.[6] Since acetone evaporates rapidly and has a flash point of 0°F and an LEL of 2.2%, a safety factor of 10 should be used. In operation, as little as possible of a solvent like acetone should be permitted in the glove box at any one time.

7.2.2 Heat Dissipation

Many glove box operations generate heat. High temperatures within the box cause a worker's hands and arms to perspire heavily within the gloves, thus lowering his efficiency. For worker comfort, sufficient air should be circulated through the box to limit the inside temperature to no more than 15°F above room temperature. When the calculated airflow rate for cooling exceeds one air change per minute, consideration should be given to supplementary cooling, better insulation of heat sources, recirculating coolers, chill blocks for hot materials, or decreasing the generation of heat by the intermittent operation of equipment. There are practical limits to the amount of cooling that can be accomplished by airflow, since high airflow rates create strong air currents that interfere with delicate work such as weighing, dispensing liquids by dropper, and handling light powders. Where possible, operators should be protected from objectionable sources of radiant heat by surrounding the heat source with reflective

shields or conductive jackets. Exhaust air streams may be routed through such shields to permit the maximum pickup of convected heat before leaving the box.

When heat transfer rates to the box atmosphere have been determined, the required cooling airflow rate to dilute the hot gases is calculated from the equation

$$Q = \frac{H}{C(t_2 - t_1)} \, , \qquad (7.3)$$

where

Q = airflow, cfm;
H = sensible heat change (by convection), Btu/hr (1 W = 3.41 Btu/hr);
t_1 = temperature of entering air, °F;
t_2 = desired average air temperature inside box, °F;
C = conversion factor for sensible heat change for air, Btu/(cfm)(hr)(°F) = (density) (specific heat) (60 min/hr).

Both the density and specific heat of air at room conditions depend on the humidity ratio of the air. The density also depends on temperature. In a room at 75°F and 50% relative humidity, the air density is 0.073 lb/ft^3 and specific heat is 0.24 Btu/lb. Therefore C is 1.1 Btu/(cfm)(hr)(°F) and Eq. (7.3) becomes

$$Q = \frac{H}{1.1 \, (t_2 - t_1)} \, . \qquad (7.4)$$

Long-term operation of high-heat-producing equipment can damage filters when exhaust air temperatures approach the temperature limit of the filters for continuous exposure to heat (see Tables 3.4 and 3.5).

7.2.3 Empirical Flow Rates

It is often necessary to establish glove box flow rates from working experience, without knowledge of the specific operation or the equipment that will occupy the box. Forty air changes is a reasonable rate for establishing ventilation-system airflow capacity.

In actual box operations, airflow rate is more likely to be reduced than increased from design rates. Normal airflow from each box on a manifold system

can easily be reduced by a factor of as much as 10, without difficulty, if a properly controlled and filtered bleed system is provided. Doubling the design airflow from each box on a manifold system may be impossible without major revision to the equipment and ducting.

7.2.4 Exhaust Requirements

The maximum airflow rate from the glove box determines the required capacity of the filters and determines the size of the equipment for the entire downstream portion of the ventilation system. The airflow resistance of the exhaust-air path must be sufficiently low so that the pumping of gloves by personnel conducting operations in the box will not result in pressurization. In small, low-flow boxes without air inlets, such as inert atmosphere types, pressure surges due to glove pumping may be a serious problem. Fast inward movement of the gloves (i.e., pumping) can cause pressure pulsations in a small box which overcome pressure differentials as slight as −0.3 in.wg, whereas differentials greater than 1.0 in.wg will cause gloves to become stiff and tiring to use. Delicate operations are more difficult to perform at high pressure differentials because operators lose much of their sense of touch when gloves separate from the fingers and then expand into the box when hands are removed.

The maximum rate of exhaust flow from an air-ventilated glove box is usually based on the required inlet flow when a glove is ruptured or inadvertently removed. The air velocity into the open port should be 100 fpm or greater. For an 8-in.-diam glove port opening, 100 fpm corresponds to a flow rate of 35 cfm. Good contamination control is more easily achieved in a glove box having low air leakage. Glove boxes should have leakage of less than 0.01 box volume per hour, when tested at 1.0 in.wg pressure differential to the outside, to be suitable as primary containers for hazard class 1 or class 2 (Sect. 2.2.1) materials. This basic leaktightness requirement aids the achievement of a suitable working negative pressure in a glove box, since little air must be exhausted to maintain the proper differential pressure. A requirement for greater leaktightness may be needed when it is necessary to exclude air or moisture in special atmosphere boxes, or to otherwise enhance containment. Glove box construction features are described in USAEC Report TID-16020[1] and other publications.[2,7-9] For inert-atmosphere glove boxes, construction requirements to control

atmospheric purity, leakage, and pressure regulation are more critical than for air-ventilated boxes.

7.2.5 Vacuum- and Pressure-Surge Relief

Glove boxes must be protected against physical damage resulting from excessive pressure or vacuum. An exhaust manifold and inlet supply system must be able to handle slowly manifested pressure or vacuum disturbances. As pressure and vacuum transients become more rapid, distant control devices become less able to maintain the box differential pressure at or close to equilibrium, and the box may be subject to structural damage. Maintaining a safe differential pressure becomes more difficult as box leakage, flow rate, and free volume (i.e., volume not enclosed by equipment within the box) decrease. Pressure surges are of particular concern in high-purity (extremely low-leakage) glove boxes.

Each glove box that contains service connections or internal equipment whose malfunction might cause a pressure surge should be equipped for prompt surge relief. The response time and pressure-flow characteristics of the surge-relief device will depend on the flow and pressure characteristics of the pressure source, the free volume, and the relative strength of the glove box. The relative strength is defined as the lowest pressure differential that will cause rupture of the glove box pressure boundary at its weakest point (e.g., the failure of a glove or window). Depending on the design of the box, the weakest point may be a window, an inlet filter, or a glove. Since inlet and exhaust connections may be shut off when a surge occurs, a conservative approach to surge-relief design is to neglect the normal inlet- and exhaust-flow capacity. The surge-relief device can be a liquid-filled U-tube, as shown in Fig. 7.3. The surge-relief flow capability should exceed the flow from the largest possible source of pressurization at the design relief pressure. The HEPA-filtered surge-relief line should not be connected to a glove box exhaust manifold, because this line will be subjected to the same pressure as the normal glove box exhaust connection. For the relief device in Fig. 7.3, a liquid storage reservoir is provided to handle the blown seal fluid. The filter should be protected from impingement of the seal fluid. If room air cannot be tolerated in the glove box, as is the case in some inert-atmosphere applications, a different vacuum surge-relief system must be used. A U-tube can be devised to restore its seal after relieving the surge, but such a system must include a feature to alert the operator that a pressure surge has occurred so that he may make necessary

safety checks. The NASA-devised vent cover[10] shown in Fig. 7.4 may be used for pressure-surge relief (or separately as vacuum-surge relief at the in-box end) following a HEPA filter. An inlet filter may provide surge relief if no backflow device or other restriction is provided. The filter-face area would have to be about four times the area of an unfiltered port to achieve equal venting effect.[11]

Explosion venting is not covered in this handbook. NFPA 68[12] contains information on explosion venting, with over 70 references. Concerning explosions, emphasis should be placed on prevention and not on
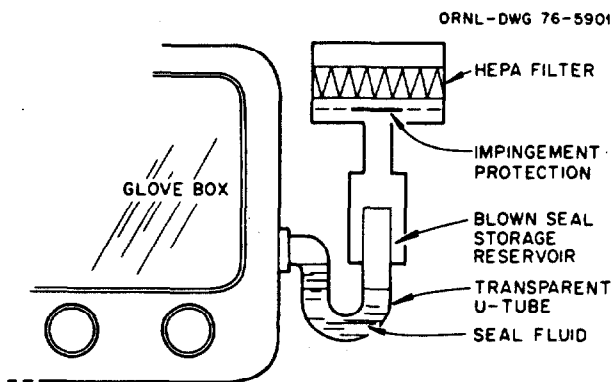

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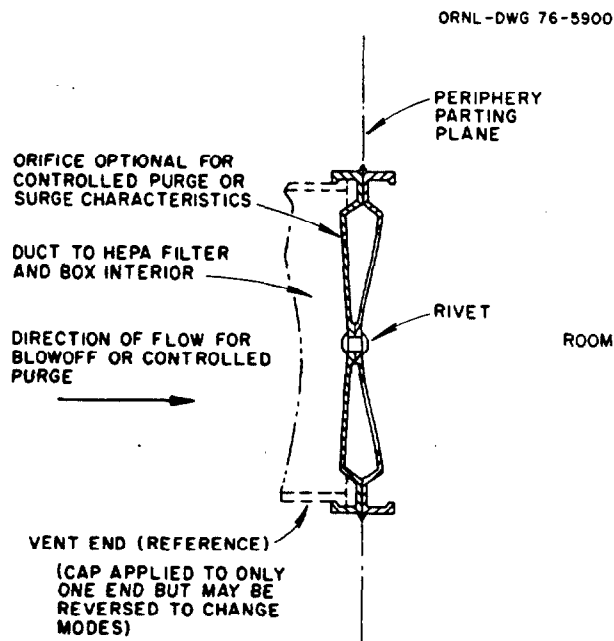Fig. 7.3. Glove box vacuum-pressure surge-relief device.

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Fig. 7.4. Pressure surge-relief cap. Cap may be repositioned for vacuum relief service.

postoccurrence treatment. *Glovebox Fire Safety*[9] contains a short section on glove box explosion suppression, with the warning that the use of such systems remains largely on an experimental basis.

7.2.6 Glove Box Exhaust Manifold

The glove box exhaust manifold includes all of the glove box exhaust system downstream from the point where the exhaust from two or more boxes joins and the flow is no longer separated. Glove box exhaust manifolds are discussed here to the extent of providing proper perspective to the importance of the HEPA filter in the safe operation of the glove box. Sections 7.2, 7.3, and 7.4 and refs. 1, 2, 8, 9, and 12 of this chapter discuss details of the exhaust system and illustrate working examples.

The glove box exhaust manifold draws air or exhaust gas from each connected box at a controlled pressure and flow (interdependently), houses secondary treatment facilities, and transmits the air for further treatment or exhausts it to the outside atmosphere. Primary exhaust treatment should be applied inside or as close to the glove box as possible and, in all cases, prior to the connection of the exhaust line to the exhaust manifold. In some systems, a portion or most of the cleaned exhaust gas may be recirculated back to the glove boxes.

The manifold system should be sized and controlled to accept a range of flow whose high extreme is the sum of (1) the maximum normal flow from each box (Sects. 7.2.1, 7.2.2, and 7.2.3), (2) the largest maximum flow under removed glove conditions from one of each five connected boxes (Sect. 7.2.4), and (3) an allowance for system growth. The low extreme is the summation of the minimum flows from each box. An allowance for system growth should be provided at not less than 20% of (1) plus (2) above for a new system. If this allowance exceeds 50% of (1) plus (2), other provisions, such as installing an equivalent dummy flow, should be considered.

Filter installation in a glove box exhaust manifold should resemble those described in Chap. 6. Prefilters may be unnecessary for the manifold system since this is the second HEPA filter the exhaust gas enters. Prefilters, if furnished, should precede the first HEPA filter if they are to serve their primary function. The provision of prefilters for fire protection of the manifold HEPA filters should be considered, as discussed in Sect. 9.5. Exhaust fans should be downstream of the HEPA filters.

Shutoff suction pressure of the fan should preferably be less than the failure pressure of the weakest component of all items upstream, including the connected glove boxes. However, system dynamics and pressure-flow characteristics for normal and emergency conditions may preclude the use of such a fan. If the fan shutoff pressure exceeds the failure pressure of the weakest component, the excess should be as small as possible. This recommendation assumes a wide-open exhaust duct, without controls or safety bleeds, and is aimed at providing an inherently safe, ideally fail-safe system. Exhaust gas-cleaning requirements may render this recommendation unattainable without adding inordinate size, complexity, and cost to the system. Nevertheless, when possible, this fan-pressure limitation should be considered. The use of positive-displacement blowers with air-ventilated glove boxes should be avoided, because these blowers are inappropriate for once-through glove box exhaust service. Positive displacement blower systems depend on external devices to limit the negative pressure attainable, especially under low or no-flow conditions, and can produce greater pressure differentials than those produced by other exhaust gas movers. Specification of too high a maximum pressure differential is potentially more dangerous to a system than overdesign of an attainable flow.

7.2.7 Exhaust Cleanup Requirements

Each particulate radioactive nuclide that might be present in the gas exhausted from a nuclear facility has a limit of acceptable concentration, as discussed in Sect. 2.2.1. The number of HEPA filter stages required in a glove box exhaust stream is a function of the permissible concentrations, in air, of the nuclides that will be in the subject exhaust stream, the decontamination factor achievable by the filter series (Sect. 2.6.2), and a safety factor for ALARA considerations discussed in Sect. 2.2.1. The fire protection scheme selected for the glove box filters may also affect the number of stages of filtration, in that it might be assumed that a stage preceding the final stage of filters is breached as a result of a fire. Occasionally, more HEPA-filter stages than necessary are installed in an attempt to increase reliability (see series redundancy, Sect. 2.6.1). The stages that follow the first-stage HEPA filter do not have to be in the immediate vicinity of the glove box being ventilated. The glove box exhaust is preferably ducted to a filter room remote from the room in which the glove box is located. This arrangement

gives more space and facilitates the maintenance and testing of HEPA filters downstream from the glove box HEPA filter. One ERDA contractor has developed criteria for new glove box facilities, in which service space is equal to the operating space and about 4C% of the service space is occupied by ducts, plenums, and ventilation equipment.

When corrosive gases or vapors are in the exhaust airstream, all filters in a series will be exposed. The widely held impression that the life expectancy of a group of HEPA filters arranged in series is directly proportional to the number of filters in the series may be false when chemical or heat degradation occurs. Under these conditions, when the first stage fails, there is a potential for others to fail from the same cause. Corrosive gases and mists from vats, scrubbers, and similar equipment must be neutralized and removed before they reach the HEPA filters.

The benefit of two or more filter stages cannot be realized unless each stage is kept in serviceable condition. Therefore, each stage of HEPA filters must have built-in provisions for routine in-place testing. (In-place testing of glove box filters is covered in Sect. 7.5.4.) The detection of damaged filters by monitoring airflow resistance is ineffective and hazardous.

7.3 DESIGN OF FILTER SYSTEMS

The glove box filter systems discussed in this section, for the most part, are first-stage HEPA filters, although second-stage filters located upstream from the exhaust manifold connection are also discussed.

Filters must pass the correct flow (with as few flow controllers as possible) when they are either clean or dirty. A maximum dirty-filter resistance of three times clean-filter resistance for HEPA filters and two times clean-filter resistance for prefilters is generally used for design purposes. Figure 7.5 gives the approximate airflow and pressure-drop relationships for clean open-face HEPA filters. Figure 7.6 shows common locations for HEPA filters near or inside glove boxes. Type 2C shows the installation of inlet and exhaust filters inside the glove box.

7.3.1 Exhaust HEPA Filters

A detailed discussion of filter performance and materials of construction is given in Sect. 3.2. Operational experience with a particular system is the most reliable basis for filter selection for a particular
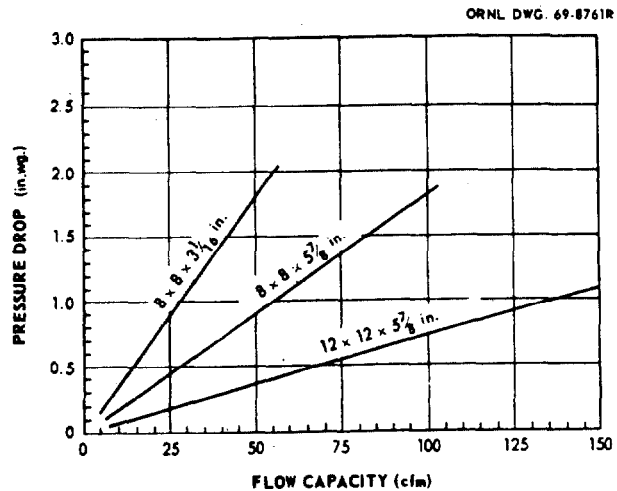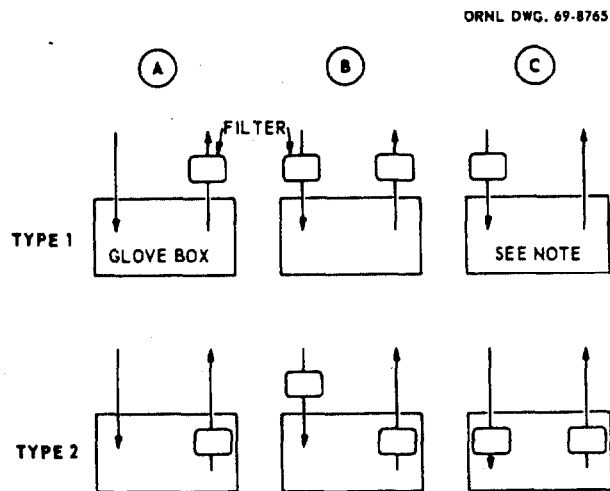

Fig 7.5. Flow vs pressure drop relationship for small, clean open-face HEPA filters. Based on air velocity of 5 fpm through the medium at nominal airflow for filter.

NOTE: TYPE IC IS NOT SUITED FOR CONTAINMENT OF RADIO-ACTIVE MATERIALS WITHIN THE GLOVE BOX BUT IS APPLICABLE WHERE THE INTENT IS TO EXCLUDE AIR-BORNE PARTICLES FROM THE GLOVE BOX SPACE.

Fig. 7.6. Possible arrangements of filters near or inside glove boxes.

service. For new and untried systems, the initial choice should be limited to the traditional rectangular, open-face, pleat, and separator construction (Sect. 3.2). Adoption of new types of HEPA filters with special features, size, or materials can result in uneconomical and unreliable system operation. The susceptibility of some nonstandard filters to deterioration in certain environments and the inability to readily obtain replacements have

presented problems to operators. If exhaust streams are kept chemically neutral, as they should be for reliable exhaust-system operation, HEPA filters of standard construction usually afford the most economical service.

A single-HEPA-filtered exhaust path is usually acceptable when work within the glove box does not involve highly toxic aerosols and does not require continuous cooling or dilution of vapors. When continuous airflow is essential, two exhaust connections should be provided to avoid interruption of exhaust flow during a filter change and to provide standby protection in the event of system upset. The purpose of multiple exhaust connections is lost unless all filtered paths are kept in serviceable condition so that a standby connection is always ready during an emergency. Figure 7.7 illustrates single- and multiple-filtered exhaust connections for a glove box.

The safety value of multiple-filtered exhaust connections can be realized easily in a line of interconnected glove boxes or in a large enclosure with several compartmented work areas. Compartmenting doors between work areas or between single boxes in an interconnected line must not isolate a work area with only one filtered exhaust connection. The multiple exhaust points required to handle total airflow in a line of interconnected boxes must be sized for maximum flow and valved individually for flow control. Current ERDA philosophy is to discourage long lines of interconnected glove boxes. Where they are necessary, fire doors between boxes should be provided.

The designer of equipment to be used in and around glove boxes must understand and respect the limitations of the human body. Past experience often reflects a lack of appreciation for these limitations.
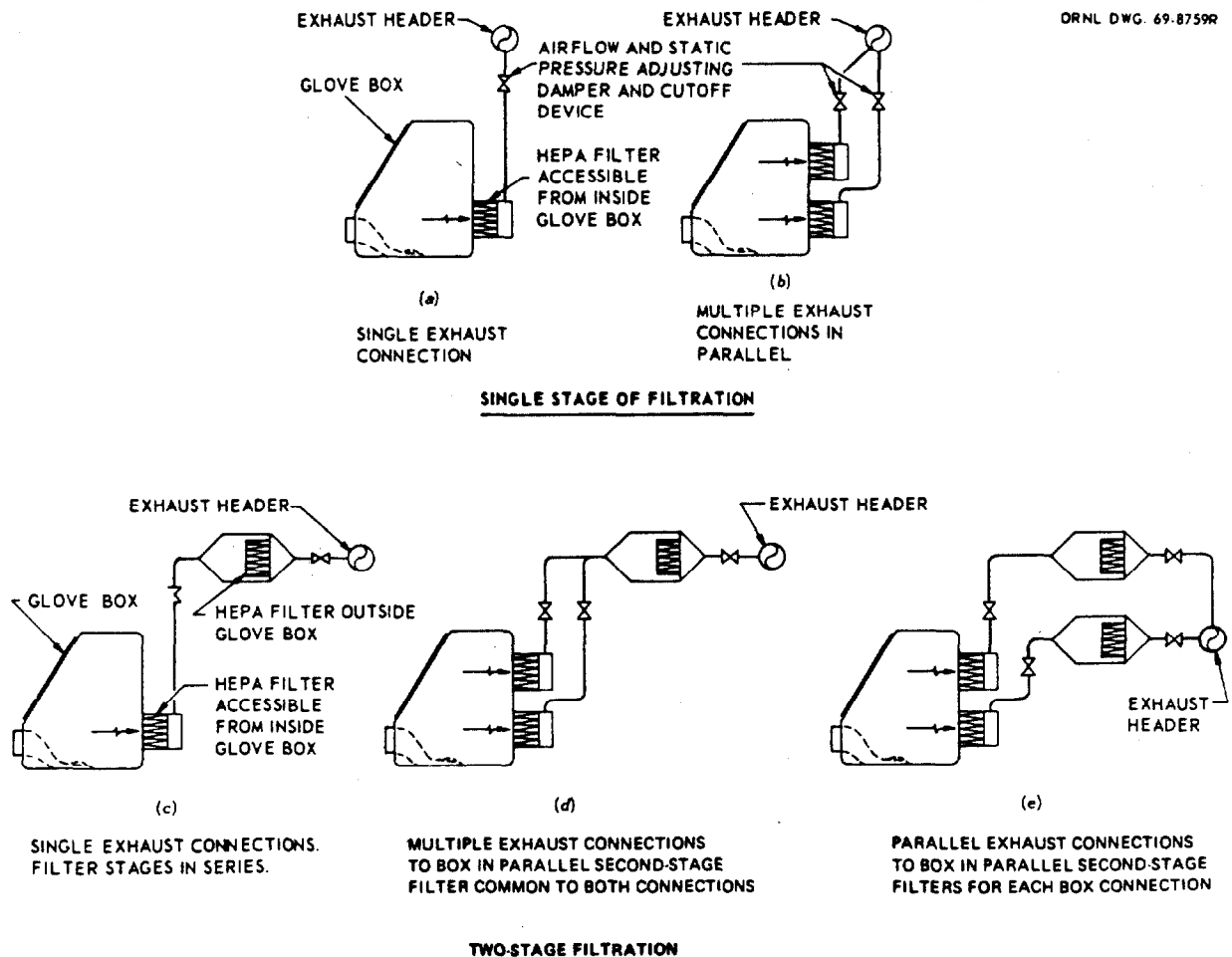

Fig. 7.7. Suggested arrangements for single- and parallel-filtered exhaust connections for glove boxes.

Tasks beyond the worker's reach or out of his sight and objects too heavy to lift readily at arms length impose unsafe conditions and lead to the neglect of items that are difficult to maintain. Working within an enclosure with hands covered by full-length flexible gloves limits the use of the senses. The required depth of reach into an enclosure should be limited to between 6 and 22 in., as shown in Fig. 7.8. A depth reach less than 6 in. allows little working room, while a depth from 22 to 29 in. is difficult and tiring; a depth reach over 29 in. makes manipulation impossible. The nominal limit for the coordinated use of both hands is a depth reach of 25 in. Figure 7.8 shows other critical dimensions for operators in and around glove box equipment. The dimensions shown are based on values that are convenient for 95% of adult males.[13]

7.3.2 Exhaust Filter Located Inside the Glove Box

The arrangement of filters inside glove boxes must be convenient and safe for the operator. The designer must thoroughly study the planned location and operation of process equipment to be certain that in-box filters are properly located with respect to airflow and do not impede the functioning of the box. The
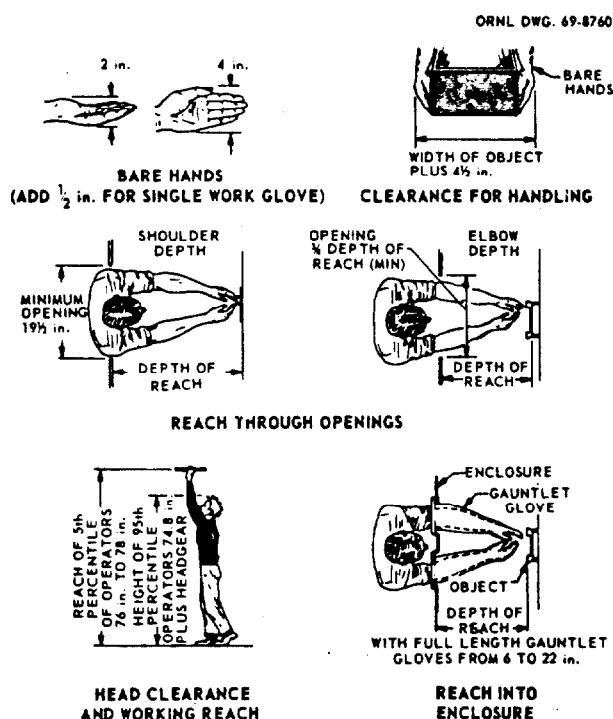

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Fig. 7.8. Dimensional guide of critical work limits for male operators in and around glove boxes.

filters must be located for convenient maintenance, testing, and inspection and still be protected from splashing liquids, flying missiles, and areas of great fire potential.

The largest HEPA filter installed inside a box is usually $12 \times 12 \times 5\frac{7}{8}$ in. Larger filters are impractical because safe handling may require special internal equipment, the filter would occupy too much space, and removal and replacement would require access ports that are too large.

Filter installation inside a glove box permits the handling of highly contaminated filters within an acceptable containment, minimizes direct contact of personnel with collected material, and permits the capture of airborne particles as close to their source as possible. On the other hand, the glove box is the focal point of the work to be accomplished, and its interior space is expensive, including any volume occupied by an in-box filter. Glove boxes are estimated to cost $500 per ft^2 of floor area and $146 per ft^3 of volume.[14] Box interior space costs exceed the cost of the operating area in which the glove box is installed by 5 to 10 times. Also, because work goes on in close quarters, the filter is more liable to be damaged inside the box; removal and replacement of filters interfere with glove box operations and are more time-consuming and tedious than for filters mounted outside the box.

Figure 7.9 shows a typical mounting for an open-face HEPA exhaust filter in the back- or sidewall of a glove box. A perforated retainer plate guards the open face of the filter. A prefilter is needed only when airborne particles are large enough to make it worthwhile (Sect. 7.3.6). The wall of the box serves as the sealing face for the filter gasket. Box wall flatness and dimensional stability are needed for good gasket seating. To change the filter the operator removes the four wing nuts and perforated faceplate to free the filter. The wing nuts must be large enough for gloved-hand operation. When a filter is mounted against the backwall of a glove box, it reduces available workspace, especially when the filter is located directly opposite a glove station. Less workspace is lost if the filter is mounted to the immediate right or left of the glove station. Addition of an extra glove can often improve access and further reduce the consumption of prime space by the filter.

Figure 7.10 shows another method of mounting open-face HEPA filters inside a glove box. By having a separable exit box, this type of inside mounting permits the filter assembly to be relocated to accom-

modate changes in box use. The assembly is supported by the 2-in. pipe that protrudes through the wall of the glove box. However, the filter sealing
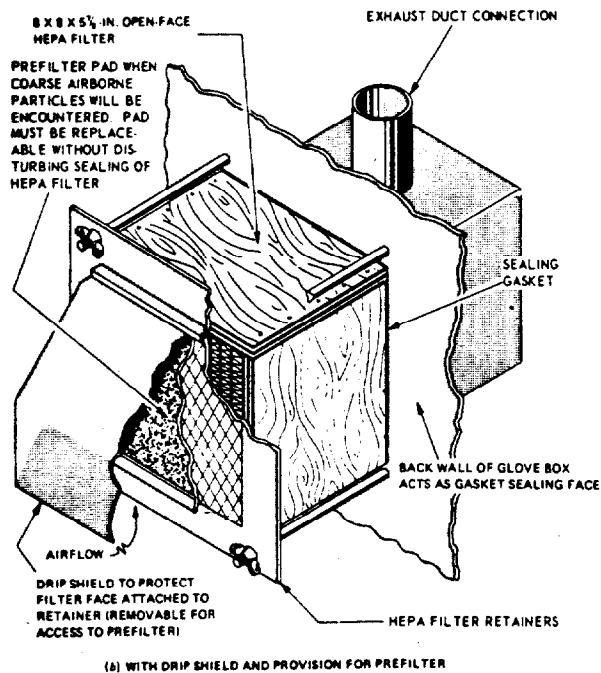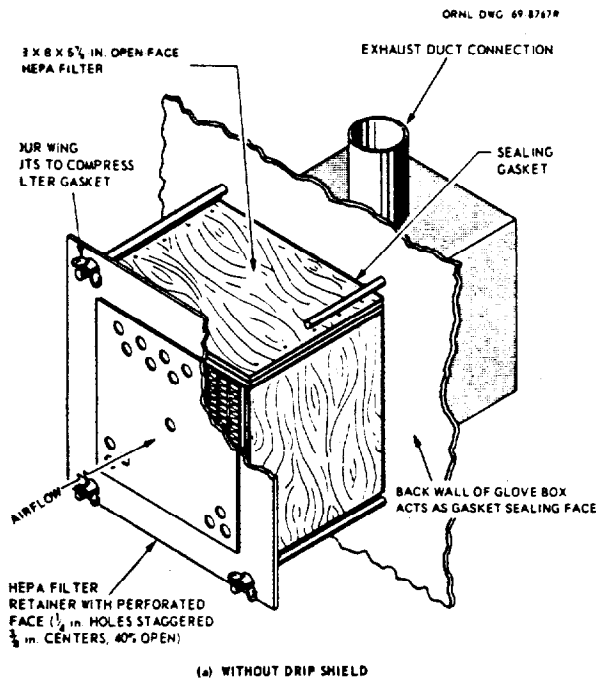
gasket is not visible for inspection in this arrangement. This mounting method is a companion to the inlet-air-filter mounting shown in Fig. 7.11, which uses accessories of identical design. The similarity of inlet- and outlet-filter mounting designs reduces the number of different parts that must be kept on hand.

Fire-resistant adhesive tape has often been used for sealing in-box filters. Gaskets are not used, and the weight of the filter is supported by a ledge or niche on the box wall. Filters installed in this way can leak seriously when subjected to heat or other disturbance that might displace the tape. Even under favorable environmental conditions, the tape peels and tends to fail after a period of time. The use of tape sealing should be limited to low-level contamination systems where leakage can be tolerated and fire potential is nil.

Figure 7.12 shows several desirable features of a good in-box filter installation. The design

- uses a standard-size HEPA filter located in the back- or end-wall of the glove box;
- maximizes inside box space by partially recessing the filter in the wall;
- has a simple clamping method with no removable pieces and is operable with a gloved

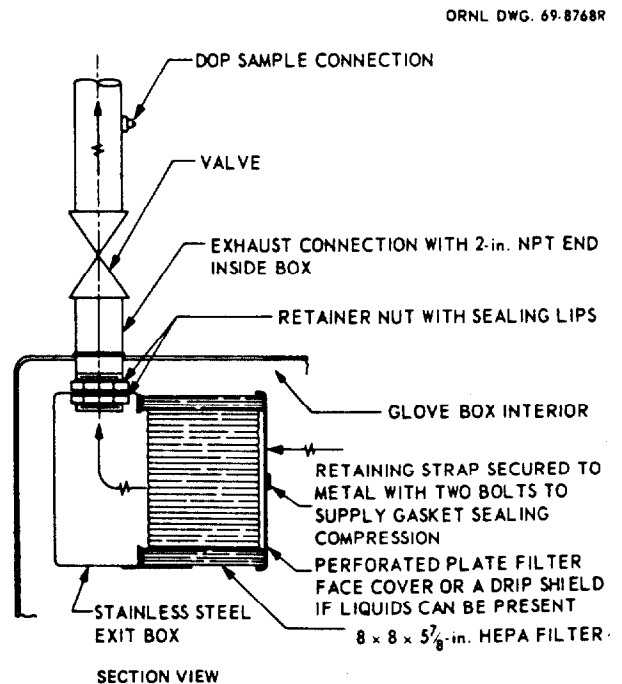Fig. 7.9. Recommended methods for mounting open-face HEPA exhaust filter inside glove box (in-box).

Fig. 7.10. Open-face HEPA filter with exit box mounted inside glove box (in-box) for exhaust service.
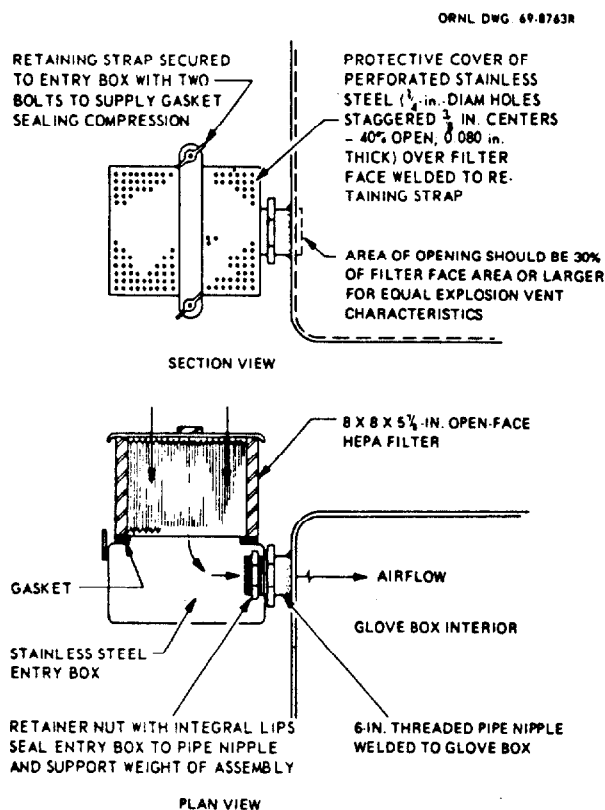
Fig. 7.11. Glove box air inlet with HEPA filter.

filter sealing faces and mounting devices for glove boxes are the same as those for mounting frames in multiple-filter systems given in Table 4.2. Where the mounting is an integral part of the glove box, construction tolerances must also be consistent with those of the box but never more lax than those values given in Table 4.2 if high-efficiency performance is to be attained.

Bag-out port sizes necessary for the transfer of standard open-face HEPA filters are given in Table 7.1.

7.3.3 Exhaust Filter Located Outside the Glove Box

The advantages of outside filter mounting include better fire protection for the filters (space available

hand by actuating a spring-loaded (snap-over-center), easily replaceable cam latch on each side of the filter;

• has a retainer that serves as a face shield for the filter and permits attachment of a steel-cased prefilter by a flexible magnetic strip (accessible from the front); the filter remains in position after being unclamped because of the folded lip at the top.

A general drawback of this arrangement is the inability to inspect the gasket and sealing-face area while the filter is in place; there could be other drawbacks for specific applications. Unfortunately, there is no single mounting arrangement without some disadvantages, and an intelligent compromise must be made for each application.

The construction materials used for filter mounting devices and associated hardware inside the glove box must provide an operating life equal to that of the box, unless the parts can be easily removed and replaced. Stainless steel should be used for bolts, latches, and other moving parts and for items that must resist corrosion. Dimensions and tolerances of
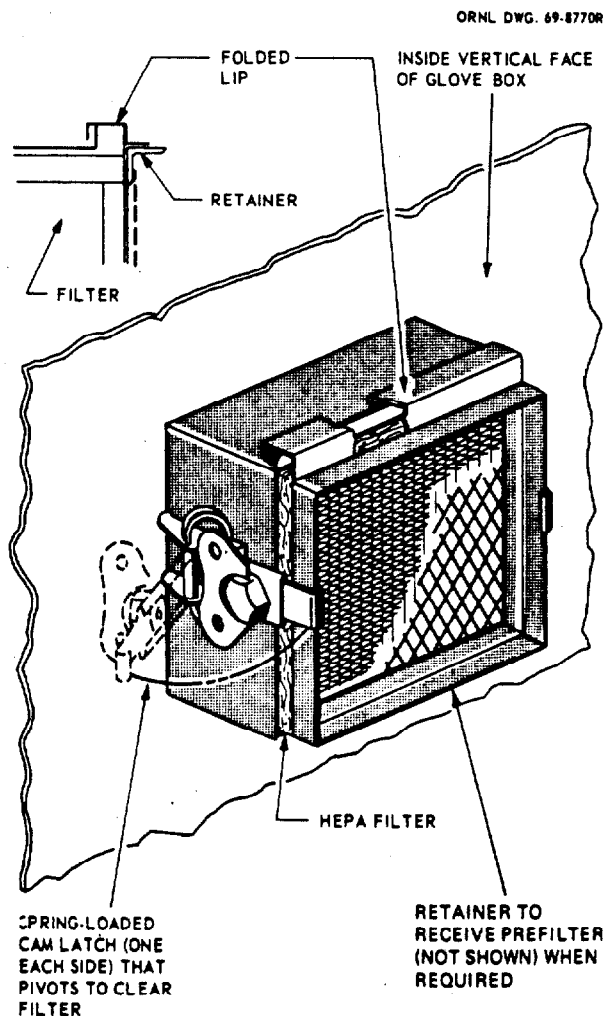

Fig. 7.12. Inside glove box open-face HEPA filter mounting arrangement with cam latches.

Table 7.1. Glove box port sizes for transfer of standard open-face HEPA filters

Filter size	Required port size (in.)	
	Round (diameter)	Rectangular
8 × 8 × 2¹/₁₆	9³/₄	8¹/₂ × 4¹/₂
8 × 8 × 5⁷/₈	10³/₄	8¹/₂ × 6¹/₂
12 × 12 × 5⁷/₈	14	12¹/₂ × 6¹/₂
24 × 24 × 5⁷/₈	26	25 × 6¹/₂
24 × 24 × 11¹/₂	27³/₄	25 × 12

for fire shield, surrounding space more readily sprinkled, etc.), conservation of in-box space, easier handling, less interference with glove box operations, and lower cost. Outside filter mounting does not automatically provide these advantages; a poor mounting arrangement can create serious handling problems and can compromise the containment of the box. When installed outside the glove box, an enclosed filter may be better able than an open-face filter to hold dust and moisture particles within the casing when the spent filter is removed from the duct. Removal of a used open-face filter requires more care and preparation to ensure that contamination will not be spread during the procedure. Sections 3.2 and 6.3 provide information on enclosed filters. Both open-face and enclosed filters have been used for external installations.

For multistage filter installations, it is sometimes desirable to locate the second stage close to the glove box so that exhaust airflow can be maintained during a filter change without spreading contamination too far down the duct. However, the second filter should be located beyond the range of likely damage. Unless a specific reason exists, it is usually better to locate the second-stage filter in a service area remote from the glove box.

Two commonly used methods of outside glove box filter mounting, shown in Fig. 7.13, are not recommended except for very-low-level applications (class 4, Table 2.2). Although simple in appearance and less costly than installations in separate housings, these mounting methods make filter replacement a very tedious and delicate operation if contaminant spills are to be avoided. Because these filters are outside and near the glove box, the risk of contaminating the local area is higher than for housings such as those shown in Fig. 7.14 or the use of enclosed filters (Fig. 7.15). Filters should be located within convenient reach, especially if tools must be used and bolts removed. High locations that require ladders or

scaffolds for access are a hazard to personnel and to the glove boxes nearby (Fig. 7.8). When filters are sandwiched between two flanged faces, as shown in Fig. 7.13, the precise alignment of gasket seating surfaces is essential to ensure uniform gasket compression. Misalignment of surfaces will not only cause nonuniform gasket compression but will increase the chance of leakage at the gasket. Rigid ducting can cause bolt pull-up forces to strain the wall
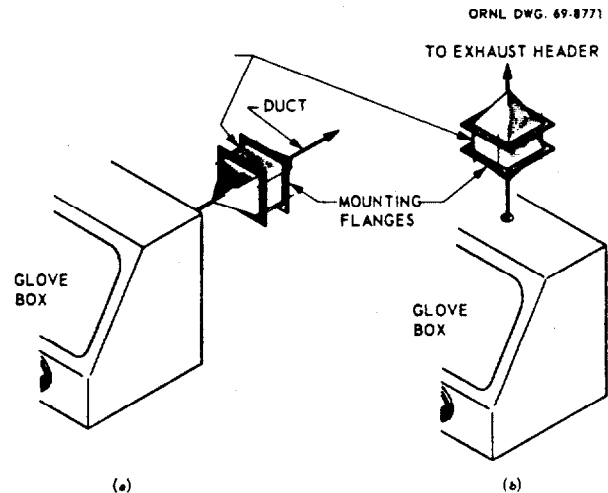
ORNL DWG. 69-8771

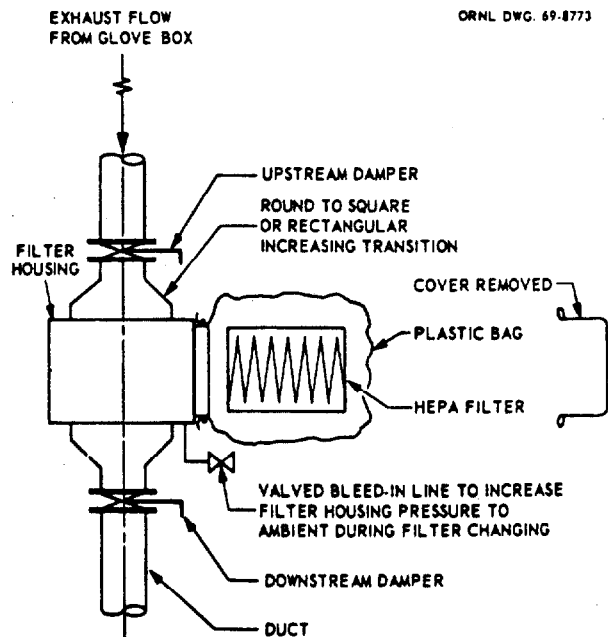Fig. 7.13. Two examples of methods for mounting HEPA filters outside glove boxes. These methods are not recommended.

ORNL DWG. 69-8773

Fig. 7.14. Typical connection for a single-filter housing in a glove box exhaust stream.

METAL COUPLING WITH RESILENT
SEAL IN EACH END

ENCLOSED HEPA
FILTER

INSTRUMENTS TO INDICATE
DIFFERENTIAL PRESSURES:
GLOVE BOX TO ROOM; ACROSS
FILTER. (MOUNTING BRACKET
NOT SHOWN)

SIDE-WALL STATIC
TAP

FLEXIBLE HOSE TO
EXHAUST CONNECTION
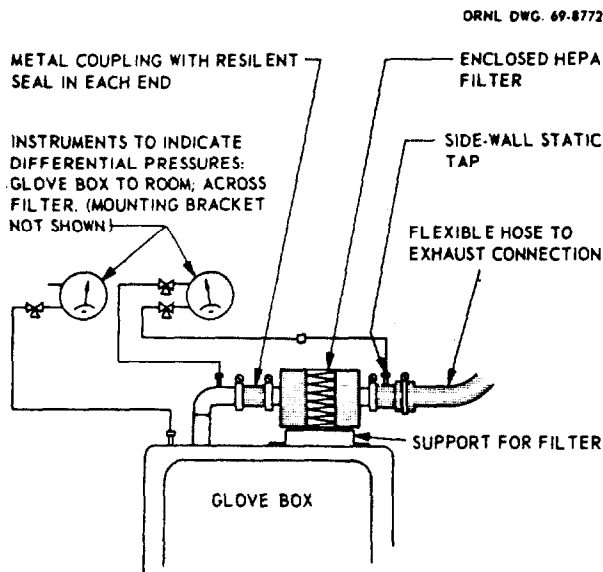
SUPPORT FOR FILTER

GLOVE BOX

Fig. 7.15. Installation of an enclosed HEPA filter mounted outside the glove box.

of the glove box or the joints in the ducting. Pull-up forces for double-gasket mountings are significantly greater than for single-gasket mountings. A short section of cuffed flexible hose on the downstream side of the filter is one method of relieving strains, but it does nothing to decrease the required gasket sealing forces. Nonmetallic flexible hoses lessen the integrity of the exhaust system because of the vulnerability of the hose to fire, accidental tearing, or penetration. Use of hoses is not advised in hazard class 1 and 2 (Table 2.2) systems. The use of nonmetallic hoses is less objectionable when there is a rigidly mounted HEPA filter between the box and the hose. Experience has clearly shown that wood and steel filter casings can be damaged by excessive pull-up. Wood casings will take greater longitudinal (i.e., face-to-face) loadings than steel casings.

Much operating experience has been gained relevant to the use of enclosed HEPA filters outside glove boxes. Figure 7.15 shows a typical installation. Although flanged and nipple-end enclosed filters have both been used, nipple-end enclosed filters are easier to install. The integral casing caps help enclose the dirty filter medium and make filter changing a less difficult and risky task than with open-face filters. In the system shown in Fig. 7.15, the exhaust ducts are flexible hoses with cuffed ends sized to fit the nipples of the enclosed filter. Initial installation costs of enclosed HEPA filters are less than those for separate filter housings.

The important features of a bag in, bag out filter installation are shown in Fig. 7.14. If filter change by bagging is not necessary for contamination control, the operation can be simplified by direct handling methods and the valved bleed-in line is not needed. The arrangement for the mini-caisson housing shown in Fig. 7.16 is comparable to the arrangement shown in Fig. 7.14 except for the absence of a valved bleed-in line and a damper to permit isolation of the housing from the duct. For applications that require filters to be bagged in and out, the procedure is like that described in Sect. 6.2.3 and shown in Fig. 6.8.

There is a limited choice of commercially available prefabricated filter enclosures suitable for glove box operations. One such enclosure is the mini-caisson shown in Fig. 7.17. This housing is made for open-face HEPA filters with dimensions of $8 \times 8 \times 5\frac{7}{8}$ in. and $12 \times 12 \times 5\frac{7}{8}$ in. The unit is flanged into the duct and is designed for bag in, bag out filter change. To prevent leakage of contaminated air during a filter change, this housing must be provided with an isolation damper in the downstream side of the duct. Although not essential for most glove box service, a second damper may be desirable on the upstream side to close off negative pressure that hampers filter bagging caused by other exhaust connections serving the same glove box (multiple connections) or glove box line.

The first cost of commercial housings may be more than five times the cost for a comparable enclosed HEPA filter installation, but filter replacement costs are lower. A comparison can be made, using purchase

DUCT FROM GLOVE BOX

MINI-CAISSON HOUSING

REMOVABLE COVER
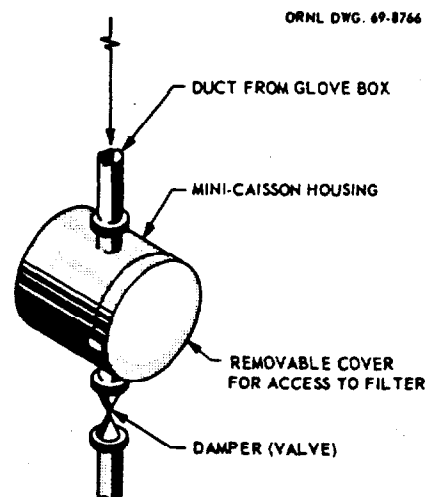FOR ACCESS TO FILTER

DAMPER (VALVE)

Fig. 7.16. Typical connections for SGN mini-caisson manufactured by Barneby-Cheney Co.

and service costs, to show how many filter changes would have to be made before the price of changing the open-face filters of a permanent commercial housing would equal the price of the same number of enclosed HEPA filters. In 1969, nine filter changes were required before capital costs were equalized. Since then, filter unit costs have almost doubled. Since relative savings will be dependent upon the frequency of filter change and the life of the

installation, the designer must consider such time factors in making any comparison. Experience at many installations indicates that the majority of HEPA filters used in glove box systems last longer than six months of continuous operation. When conditions are unusually clean or use is intermittent, as is true for most glove boxes used in research applications, they may last longer than 18 months. Using a filter change frequency of six months as a
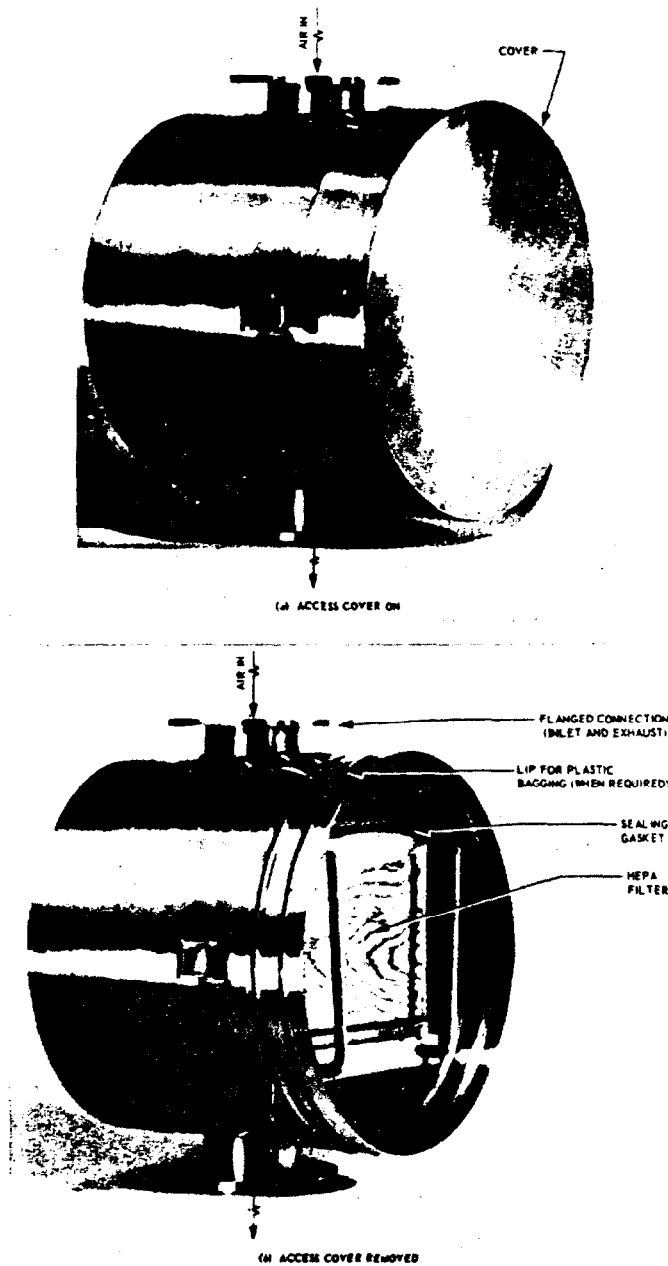

Fig. 7.17. Mini-caisson housing for open-face HEPA filters. Courtesy Barneby-Cheney Co.

basis, there is no equipment cost advantage for using a commercial housing unless the life expectancy of the installation is more than five years.

Although difficult to estimate, the total costs (installation and operating) for HEPA filters installed inside glove boxes may be less than those of out-of-box installations using commercial enclosures, if the cost of in-box space is neglected. However, total costs for in-box filter installations (using standard-sized filters) are about equal to those for installations using enclosed HEPA filters in ducting outside the glove box, again neglecting box-space cost. The cost advantages for any type of installation can easily be overruled by special operational requirements, or lack of space can make the desired installation method impractical.
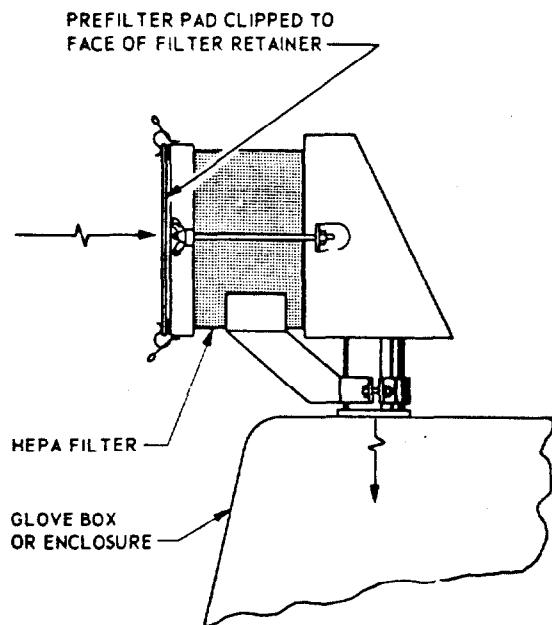
7.3.4 Inlet HEPA Filters

Work performed in glove boxes frequently requires that supply air be kept free of airborne contaminants. Inlet HEPA filters help to maintain clean conditions inside and, when chosen properly, serve three other useful functions: (1) they extend the service life of the exhaust filter by protecting them f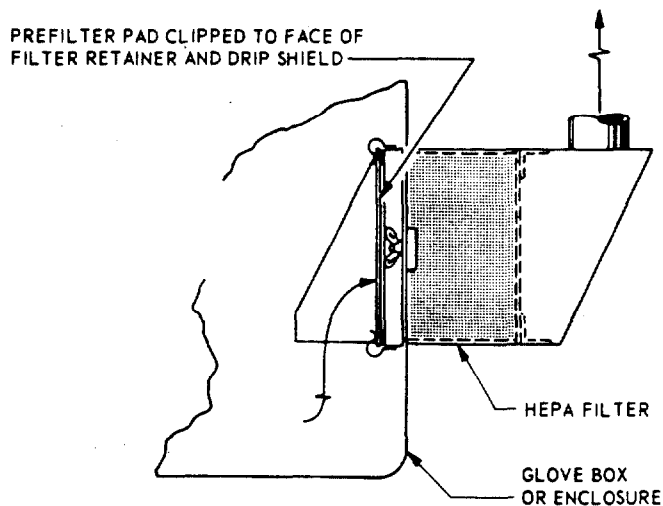rom atmospheric dirt loading; (2) they prevent the spread of contamination from the glove box to the room in the event of a box pressurization; and (3) they provide overpressure relief.

The design of the inlet filter installation is relatively simple for air-ventilated nonrecirculating glove boxes. Since no duct connections are required, open-face filters may be used with an installation and clamping method that leaves one face completely exposed. Typical methods of installation are shown in Figs. 7.11 and 7.18. Because they are less likely to be contaminated, inlet air filters are easier to replace than exhaust filters; therefore, they provide fewer problems and less risk during changes. Whether mounted inside or outside the glove box (outside mounting is preferred), the same high quality of mounting, clamping, and sealing is required.

The open face of the filter must be protected from physical damage and fire. Plugging of the inlet filter by smoke is of secondary concern, however, since one recommendation for glove box fire suppression is to reduce normal airflow. Locating the inlet connection (or an attached inlet duct) high in the box tends to reduce the amount of air drawn into the box during a fire because of the chimney effect.

ORNL DWG. 69-8764

PREFILTER PAD CLIPPED TO FACE OF FILTER RETAINER

HEPA FILTER

GLOVE BOX OR ENCLOSURE

PREFILTER PAD CLIPPED TO FACE OF FILTER RETAINER AND DRIP SHIELD

HEPA FILTER

GLOVE BOX OR ENCLOSURE

INLET AIR FILTER INSTALLATION

IN-BOX EXHAUST FILTER INSTALLATION

Fig. 7.18. Typical installations of prefilter pads on face of HEPA filters.

7.3.5 HEPA Filter Selection

The number of types and sizes of HEPA filters used at an installation should be minimized for logistical and operating economy. All HEPA filters should be of fire-resistant construction. The sizes of HEPA filters most often used in glove box systems are $8 \times 8 \times 3^1/_{16}$ in., $8 \times 8 \times 5^7/_8$ in., and $12 \times 12 \times 5^7/_8$ in. with nominal airflow capacity of 25, 50, and 125 cfm respectively. The size and number of filters required for a glove box are determined by the maximum flow requirements and the pressure differential available to overcome air resistance. Glove box filters are customarily operated at flow rates below their nominal rating. Wood-cased fire-resistant HEPA filters are less expensive and should be considered wherever the operating environment (temperature, humidity, etc.) permits.

Undesirable features of both the enclosed and open-face HEPA filters include the following:

- insufficient capacity for large amounts of dust;

- chemical fumes such as caustic hydrofluoric acid mist can destroy filter medium separators and adhesives;

- sharp corners and edges of metal casings can damage protective bagging;

- in dry atmospheres (<2% relative humidity) the plywood of wood-cased HEPA filters may shrink and delaminate, causing eventual failure of the filter. Very low moisture levels may cause a shrinkage problem for particle board casings as well. This could be an acute problem in inert atmospheres where very low moisture levels (<50 ppm) have to be maintained. In such systems, steel-cased filters should be used.

Open-face HEPA filters have the following additional shortcomings:

- more vulnerable to damage during handling and storage;

- lack of handle or gripping area for ease of withdrawal from an enclosure;

- difficult to replace damaged face gaskets.

Enclosed HEPA filters have the following additional shortcomings:

- lack UL certification;

- reeding (induced vibration of separators caused by air motion) at high flow rates is worse than in open-face filters, because the entering air impinges on a smaller area of the filter pack;

- greater weight than open-face filters (see Table 3.2 for comparison);

- substantially greater cost than open-face filters;

- greater space requirements;

- problem of air leakage with steel cases, especially in inert atmosphere and high-pressure applications;

- no visible means of detecting damage to the medium.

7.3.6 Prefilters

As in larger systems, prefilters may be used in both the inlet and exhaust air streams to extend the life of the HEPA filters used in glove box filtration systems. Prefilters are sacrificial items and the decision to use them requires that the designer evaluate the advantage of longer HEPA filter life against the problems of limited space frequently encountered in glove box systems. Prefilters attached directly to the face of the HEPA filter provide no fire protection for that HEPA filter. Glove box prefilter service often requires that filters be subjected to periods of high temperature, moisture, dust, and corrosive agents that shorten their effective life and mounting.

Experience with prefilters in glove box ventilation systems has shown the use of metal media to be impractical. Without viscous coatings the filtering efficiency of metal-media prefilters is poor, and these filters are often almost impossible to clean and decontaminate. Adhesives and oil coatings that improve particle retention reduce in-box cleanness and fire resistance. Experience clearly indicates that use of conventional types of prefilters that require cleaning or decontamination or both before reuse is impractical. Throwaway filters with simple installation methods are preferred. After use, the units are discarded as contaminated waste unless collected materials must be reclaimed. Glass-fiber-media prefilters are preferred because serviceability is good, costs are low, and combustible content is small.

Inlet airstreams with HEPA filters should be fitted with prefilters when using atmospheric air. However, when the room air has been cleaned of the bulk of its airborne dust by building supply-air systems, when local room activities do not generate dust and lint that can be drawn into the box, and when airflow

through the HEPA filter is less than 75% of its rated capacity, there may be no need for a prefilter.

A common method of prefiltering is to clip a thin ($\frac{1}{8}$ to $\frac{1}{4}$ in.) fiberglass pad to both the inlet and exhaust HEPA filters, as Fig. 7.18 shows. Neither plastic foam nor organic fiber should be used because both are flammable. The pad is cut to fit the face of the HEPA filter and is clipped to the filter retainer. This method of attachment permits easy removal of the prefilter pad without disturbing the seal of the HEPA filter. Normal usage generally requires frequent replacement of the prefilter pads, which do not have much dirt-holding capacity and can quickly become plugged by house dust and lint. Convenient methods of attaching the prefilter pads are essential. Frequent replacement of prefilter pads assures that

- air resistance (pressure drop) does not change rapidly, which thus allows airflows to remain more nearly constant without frequent manipulation of dampers;

- the accumulation of combustible dust in the exhaust path is less, thereby providing better fire protection for the HEPA filter downstream if the prefilter is not applied directly to the face of the HEPA filter;

- the exhaust path can pass a greater flow of air in relieving an emergency condition.

Fiberglass pads ($\frac{1}{4}$ in. thick or less) can provide average atmospheric dust collection efficiency up to 20% (as determined by ASHRAE 52-68),[15] with low airflow resistance. Thin ($\frac{1}{4}$ in. thick or less) clean fiberglass pads used at air velocities of 35 fpm will create an initial pressure drop in the range of 0.03 to 0.15 in.wg. Table 7.2 lists several types of media that can be used as prefilter pads.

For applications where long-term continuous processes hamper regular maintenance of in-box filters, the designer must include

- provision for greater suction pressure (well below the limit that would subject glove or box integrity to unsafe differential levels) controlled by the damper to allow for longer use of prefilters;

- provision for more prefilter area; or

- selection of a prefilter with less initial resistance to permit longer use, even though lowering collection efficiency.

7.4 FILTER REPLACEMENT

The safe replacement of a contaminated glove box filter must be planned in the design stage to facilitate proper execution. The designer should prepare a written preliminary filter change procedure along with the design documents. Because they are prepared for construction purposes, the intended operating and maintenance procedures envisioned by the designer may not always be implicit or obvious in the design drawings and specifications. By writing a preliminary filter change procedure, the designer assures himself that the changeout can be performed safely.

Crew members directly involved in a contaminated filter change must wear appropriate respiratory protection. Filters installed inside the glove box are accessible by the use of gloves on the box. When the total activity of contaminants is high, additional protective measures may be necessary to reduce worker exposure. One method of controlling the spread of contamination, while preserving the in-

Table 7.2. Prefilter pad materials

Medium	Thickness (in.)	Initial pressure drop (in.wg)	Velocity (fpm)	Collection efficiency		Remarks
				NBS[a] (%)	AFI[b] (%)	
Owens-Corning Fiberglas Corp., RE-1	$\frac{3}{16}$	0.05	35	20		
American Air Filter Co. Type G Airmat	$\frac{3}{32}$	0.03	35		87.5	UL class I rating[c]
No. 12 Airmat	$\frac{1}{4}$	0.09	35		95	UL class I rating[c]

[a]Clean efficiency—ASHRAE 52-68 test method using atmospheric dust.
[b]Average arrestance—ASHRAE 52-68 test method using synthetic dust.
[c]UL-900, *Safety Standard for Air Filters*, Underwriters' Laboratories, current issue.

tegrity of the closed box and the system, is bagging the filters in and out of the glove box, as shown in Fig. 7.19. The plastic bagging materials used are discussed in Sect. 6.2.3. When inert-atmosphere or oxygen-free environments are used inside the glove box, additional provisions may be required to prevent air leakage into the box.

Replacement of a HEPA filter inside an airventilated box entails many steps that must be performed sequentially. Each step must be carefully planned and completed in a methodical manner to preserve containment of the system. Close coordination between maintenance and operating personnel is necessary to establish a mutually satisfactory date and time for the filter change, to identify the boxes and systems involved, to procure the necessary materials, and to schedule personnel. The health and safety requirements of the industrial hygienist, health physicist, and safety engineer must be established; one of these specialists should be designated the health and safety supervisor and should be available to monitor the operation and to assist as necessary.

When the necessary materials and tools are ready and all personnel have been instructed in their specific duties, final permission must be secured from the responsible operator to alter the airflow and replace the filters. The flow path of the exhaust system should be thoroughly understood, and persons responsible for related exhaust systems that will be affected should be forewarned. For instance, if two glove box exhaust systems manifold to the same blower, final filters, and stack, the removal of one system from service for a filter change will have an effect on system flow and pressure characteristics of the other system. Safety clothing and respiratory protection should be worn as directed by the health and safety supervisor. Typical steps required to change a filter and place a box back in service are as follows:

1. Cease all glove box operations and store unsafe materials in suitable containers.

2. Cut off gas flow to the glove box affected and adjust flow through the remaining branches to

NEW FILTER BAGGED INTO CONTAMINATED ENCLOSURE

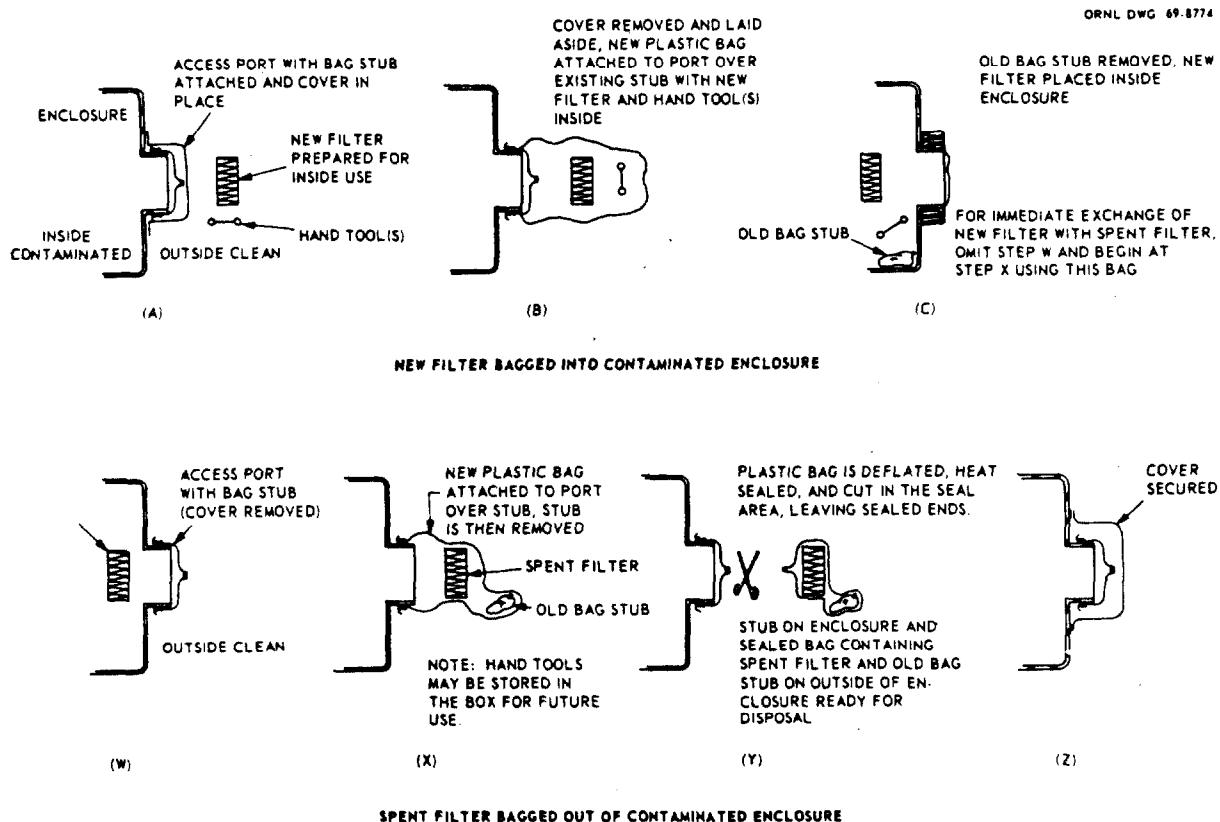SPENT FILTER BAGGED OUT OF CONTAMINATED ENCLOSURE

Fig. 7.19. Technique for changing filters installed inside contaminated enclosures.

restore a safe negative pressure and flow rate in each.

3. Bag in (a) a clean replacement filter (and prefilter if used); (b) a small, clear plastic bag and sufficient tape to hold the spent filter and prefilter; and (c) all hand tools required, as shown in steps A, B, and C of Fig. 7.19. It is recommended that hand tools needed for filter changing be introduced the first time filters are changed and then left in the glove box for subsequent use if space and environment permit. Decontamination is often more costly than replacement of tools.

4. Using the box gloves, remove the dirty filter and prefilter from their mounting frame.

5. Insert the dirty filter and prefilter into an empty plastic bag, slowly expel excess air, and seal with tape.

6. Inspect gasket sealing face of the mounting frame and clean if necessary. Place replacement filter in position and secure clamping devices. Place new prefilter in position and secure.

7. Remove the dirty filters and all debris from the glove box, as shown in steps W, X, Y, and Z of Fig. 7.19, and place removed items in a container for contaminated waste disposal.

8. Restore airflow through the glove box and adjust flow and negative pressure throughout the system.

9. Before glove box operations are resumed, test the newly installed HEPA filter with DOP, using the permanent test connections on the housing. If the test result is not satisfactory, stop the flow and inspect the filter for damage. If no damage is apparent, reposition the filter, restore the flow, and retest the filter. If the second DOP test is unsatisfactory, the filter should be replaced and steps 3 through 9 repeated. Continued leakage suggests a failure of the mounting frame or a faulty test, and each possibility should be examined in detail until the fault is discovered and corrected.

10. Decontaminate the area.

11. After successful filter replacement, notify the responsible operator.

Filters located outside a glove box require convenient access for changing, and it is usually necessary to interrupt airflow during the change. Since they are located outside the glove box, highly contaminated filters must be bagged during the change. Different bagging techniques provide different degrees of protection. The technique shown in Fig. 7.20 employs the principle of total containment when even minute leakage cannot be permitted. This method seals both ends of the air ducts, and no flow can occur downstream while the filter is removed. When uninterrupted airflow through a box is required, this method of filter change necessitates the use of multiple exhaust connections on the box. An out-of-box filter in the process of being removed from a system by the procedure illustrated in Fig. 7.20 (step 3) is shown in Fig. 7.21.

For other methods where bagging does not block the airflow path (e.g., using the housings represented by Fig. 7.14) but merely encapsulates the filter being removed or replaced, there is a dependence on the damper in the duct to prevent blow-by (leakage) during a filter change. The total containment method (illustrated in Fig. 7.20) disconnects the exhaust duct and does not depend on damper tightness. The technique of bagging filters from housings (Fig. 7.14) offers protection only for local personnel and the service area where the filter mounting device is located. The side of the system downstream of the filter is protected not by bagging but by leakproof dampers and flawless handling of the dirty filter. Because any dislodged particles will be swept downstream when airflow is restored, downstream HEPA filters should be provided to intercept these particles.

7.5 GLOVE BOX SAFETY

7.5.1 Protection Against Fire and Explosion

Fire and explosion protection has received much attention. Some useful references include:

A. J. Hill, Jr., *Automatic Fire Extinguishing Systems for Glove Boxes and Shielded Cells at the Savannah River Laboratory*. DP-1261, Savannah River Laboratory, June 1971.

C. Jackson, T. W. Hodge, D. H. Swingler, and A. J. Smith, *Some Aspects of Fires in Glove Boxes*, AERE-R 3067, United Kingdom Atomic Energy Authority, October 1959.

S. E. Smith, F. J. Hall, W. E. Holmes, and A. F. George, *Protection Against Fire Hazards in the Design of Filtered Ventilation Systems of Radioac-*
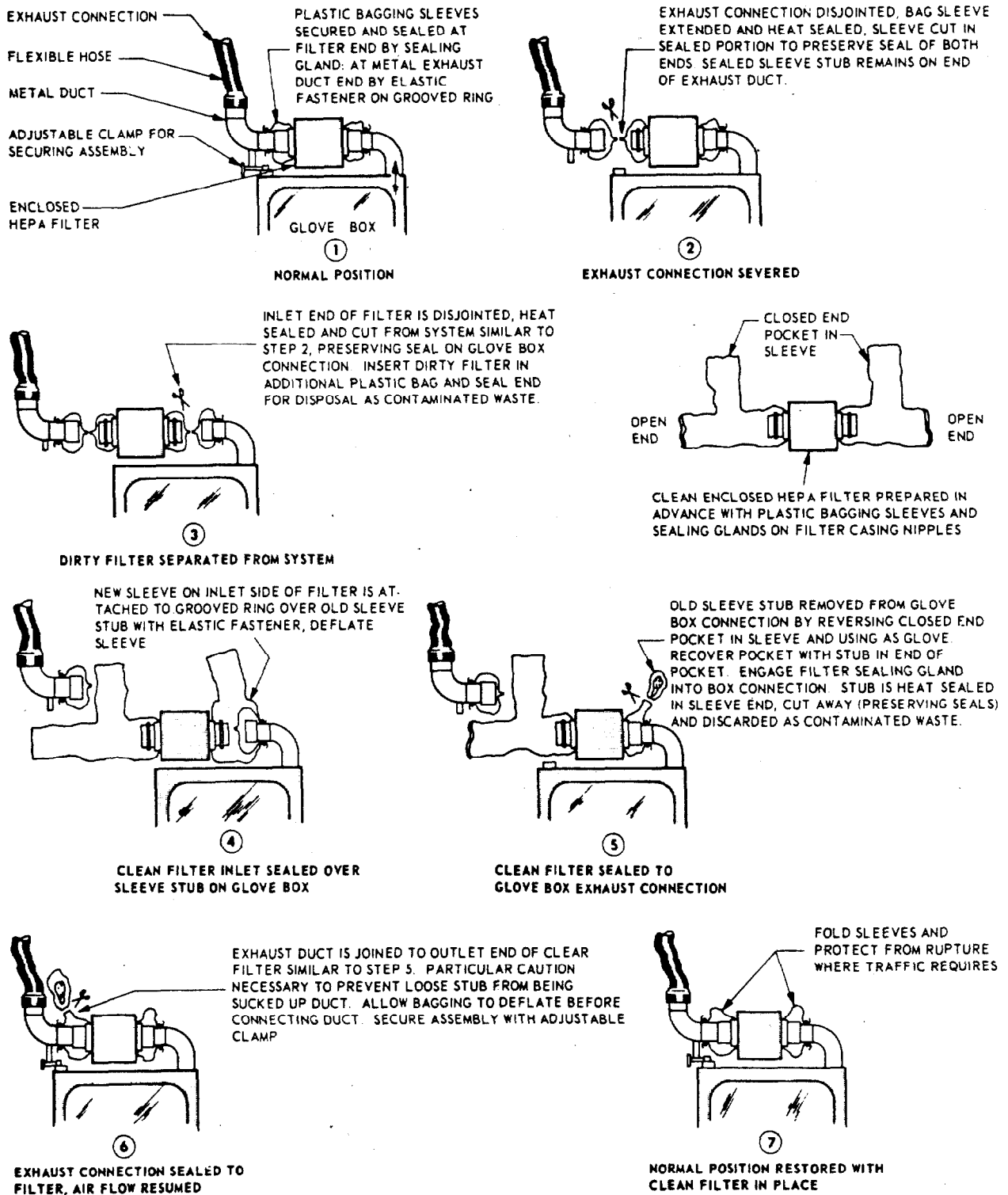
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EXHAUST CONNECTION

FLEXIBLE HOSE

METAL DUCT

ADJUSTABLE CLAMP FOR
SECURING ASSEMBLY

ENCLOSED
HEPA FILTER

PLASTIC BAGGING SLEEVES
SECURED AND SEALED AT
FILTER END BY SEALING
GLAND: AT METAL EXHAUST
DUCT END BY ELASTIC
FASTENER ON GROOVED RING

GLOVE BOX

①

NORMAL POSITION

EXHAUST CONNECTION DISJOINTED, BAG SLEEVE
EXTENDED AND HEAT SEALED, SLEEVE CUT IN
SEALED PORTION TO PRESERVE SEAL OF BOTH
ENDS. SEALED SLEEVE STUB REMAINS ON END
OF EXHAUST DUCT.

②

EXHAUST CONNECTION SEVERED

INLET END OF FILTER IS DISJOINTED, HEAT
SEALED AND CUT FROM SYSTEM SIMILAR TO
STEP 2, PRESERVING SEAL ON GLOVE BOX
CONNECTION. INSERT DIRTY FILTER IN
ADDITIONAL PLASTIC BAG AND SEAL END
FOR DISPOSAL AS CONTAMINATED WASTE.

③

DIRTY FILTER SEPARATED FROM SYSTEM

CLOSED END
POCKET IN
SLEEVE

OPEN
END

OPEN
END

CLEAN ENCLOSED HEPA FILTER PREPARED IN
ADVANCE WITH PLASTIC BAGGING SLEEVES AND
SEALING GLANDS ON FILTER CASING NIPPLES

NEW SLEEVE ON INLET SIDE OF FILTER IS AT-
TACHED TO GROOVED RING OVER OLD SLEEVE
STUB WITH ELASTIC FASTENER, DEFLATE
SLEEVE

④

CLEAN FILTER INLET SEALED OVER
SLEEVE STUB ON GLOVE BOX

OLD SLEEVE STUB REMOVED FROM GLOVE
BOX CONNECTION BY REVERSING CLOSED END
POCKET IN SLEEVE AND USING AS GLOVE.
RECOVER POCKET WITH STUB IN END OF
POCKET. ENGAGE FILTER SEALING GLAND
INTO BOX CONNECTION. STUB IS HEAT SEALED
IN SLEEVE END, CUT AWAY (PRESERVING SEALS)
AND DISCARDED AS CONTAMINATED WASTE.

⑤

CLEAN FILTER SEALED TO
GLOVE BOX EXHAUST CONNECTION

EXHAUST DUCT IS JOINED TO OUTLET END OF CLEAR
FILTER SIMILAR TO STEP 5. PARTICULAR CAUTION
NECESSARY TO PREVENT LOOSE STUB FROM BEING
SUCKED UP DUCT. ALLOW BAGGING TO DEFLATE BEFORE
CONNECTING DUCT. SECURE ASSEMBLY WITH ADJUSTABLE
CLAMP

⑥

EXHAUST CONNECTION SEALED TO
FILTER, AIR FLOW RESUMED

FOLD SLEEVES AND
PROTECT FROM RUPTURE
WHERE TRAFFIC REQUIRES

⑦

NORMAL POSITION RESTORED WITH
CLEAN FILTER IN PLACE

Fig. 7.20. Bagging technique for enclosed HEPA filter located outside the glove box.

EXHAUST DUCT WITH PLASTIC SLEEVE STUB IN PLACE

REAR SIDE OF GLOVED BOX

BOX CONNECTION SEALED WITH PLASTIC SLEEVE STUB

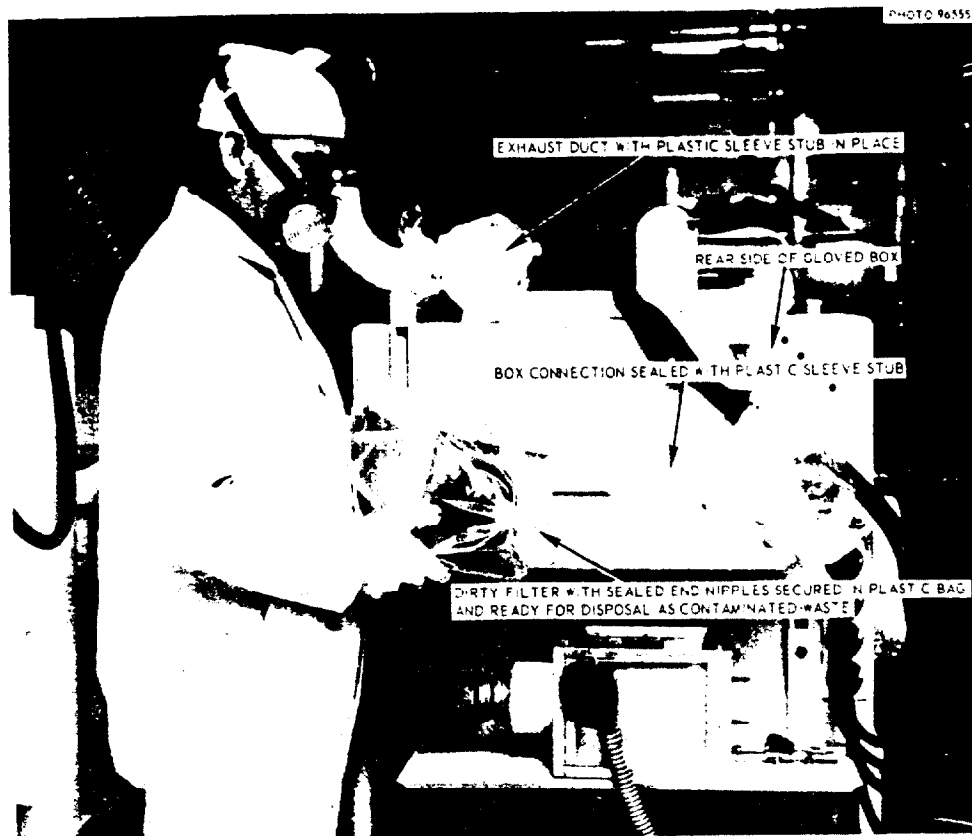DIRTY FILTER WITH SEALED END NIPPLES SECURED IN PLASTIC BAG AND READY FOR DISPOSAL AS CONTAMINATED WASTE

Fig. 7.21. Enclosed HEPA filter being removed from exhaust stream outside glove box by bagging. Courtesy Oak Ridge National Laboratory.

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The task of fire and explosion protection can be divided into prevention, detection, and suppression. These areas are discussed below as they apply to glove box operations and in Chap. 9.

Protection. Fire prevention in glove boxes is mainly accomplished by the following methods:

1. Using nonflammable materials in construction.[1,2,8,9] Gloves and windows have received the most attention, since they are the most necessary and vulnerable parts of the glove box.

2. Strict adherence to acceptable housekeeping practices.

3. Avoiding the use of flammable materials within the box wherever possible and limiting the amount of flammables to the minimum required for immediate use when no suitable nonhazardous substance can be substituted. Using containers for flammable substances that are as safe as can be found for the planned operation.

4. Maintaining a current in-box material inventory and not using the box for storage. Boxes usually are inappropriate for storage, especially for chemicals.

5. Establishing a safer, nonoperative box configuration and periodically checking to make sure that nonoperating boxes are in safe condition. Precautions include isolating boxes by closing fire stops, checking through-flow, checking port covers, disconnecting electrical equipment, and removing corrosives.

6. Designing the box with downdraft ventilation (high air inlet, low outlet), to inhibit combustion while still purging the box.

7. Providing a protective atmosphere (Sect. 7.5.2). This measure was listed last because those preceding it are applicable to all glove boxes, whereas inerting is used only when there is too much risk involved in operating without a protective atmosphere. Assessing the degree of risk involved in an operation is often a subjective evaluation.

Detection. A glove box fire detection system is recommended when there is high risk of fire. If flammable solvents, coolants, packaging materials, etc., must be present during operation and especially in unattended boxes, a heat detector should be located within the box. Regulatory Guide 3.12[16] calls for heat detectors and combustible-gas or vapor-detection meters on glove boxes wherever fire or explosion hazards exist.

Fire detectors are required in plutonium glove boxes.[17] A description of currently available detectors is given in the Factory Mutual safe practice guide.[9] Report DP-1242[18] contains a useful section on evaluating detectors.

Suppression. Since a fire within a glove box may be of paper, chemical, electrical, or pyrophoric metal origin, there is no single suppression method that is best for all glove boxes. Halon-1301[19] is an effective general extinguishing agent; it is better than carbon dioxide[20] on chemical and electrical fires but ineffective against pyrophoric metal fires;[21] and it decomposes above 750° F. The use of carbon microspheres for extinguishing metal fires is discussed in Sect. 9.5.4. The complete exclusion of oxygen with rapid heat removal to below its ignition temperature (500° C) is effective for extinguishing plutonium fires.[21]

There is no assurance that filters will remain functional during and following exposure to fire, smoke, or burning debris. The temperature reached during a fire, the quantity and density of smoke released, and the duration of the fire determine the destructive effects on prefilters and HEPA filters.

HEPA filters can withstand 750° F temperatures for periods up to 10 min but should not be subjected to indefinite exposure to temperatures higher than 275° F (Tables 3.4 and 3.5). Longer filter life and more reliable service can be obtained when normal operating temperatures are below 200° F and high temperature extremes are avoided.

The selection and arrangement of HEPA filters on, in, or near glove boxes and similar enclosures are limited by the type of fire control equipment used, because HEPA filters and most prefilters are not compatible with all types of fire extinguishing systems. Dry chemical extinguishers employ finely divided solids that can clog filters. Ideally, the

discharge point of dry chemical agents should be selected to blanket the fire zone effectively without becoming airborne.

When large amounts of carbon dioxide (CO_2) are released from a cylinder, moisture in the glove box atmosphere may form ice crystals that can clog filters after only a few minutes of operation. Should this happen, introduction of more CO_2 is likely to overpressurize or perhaps rupture the box. Carbon dioxide is a poor fire extinguishing agent for glove boxes because of its tendency to clog exhaust filters, reduce airflow, and obscure vision when moisture is present.

When foaming agents or spray droplets from fire extinguishing systems reach a filter, it is quickly clogged if free moisture cannot be evaporated into the air passing through the filter. This limits the use of foam generators and water fogs to ventilation systems where emergency devices are actuated and controlled manually, or where continuous airflow through the filter (or filters) during an emergency is not required. The standard for high expansion foam systems is NFPA 11A,[22] and for synthetic foams, NFPA 11B.[23]

7.5.2 Protective Atmospheres—Inerting

The difference between a protective atmosphere and an extinguishing agent is that the protective atmosphere prevents the fire condition from occurring, whereas the extinguishing agent is applied as a response after a fire has started. Argon, carbon dioxide, nitrogen, and helium have all been used as inerting agents. The protective atmosphere system is designed for continuous operation, whereas the extinguishing system usually has a one- or two-shot, single-incident application before reservicing is required to return the system to the ready state.

Inerting with smothering agents may require that less than 1% oxygen be present in the glove-box atmosphere. Process and product-purity considerations may require as little as 100 ppm of total atmospheric impurities within the glove box for successful operation. Since many of the detailed considerations are similar for high-purity and fire-protection inerting, and because of the widespread application of high-purity inerting, most of this discussion will involve high-purity systems. The best single reference for design, construction, and operational information is *Inert Atmospheres*[2] by White and Smith.

Inert-atmosphere glove boxes that contain radioactive material are operated at pressure differentials of 0.3 to 1.0 in.wg negative relative to the surroundings. Gas flow rate is usually determined by the atmospheric purity required and the purity of the incoming gas. The box atmosphere purity can be compromised by air leakage into the box or into service connections or leakage from process equipment in the box.

Filter installation requirements in inert-atmosphere glove boxes are more stringent than for air-ventilated boxes, because acceptable box air-leakage rates are generally less than 0.0005 box volume/hr.[2] To attain this standard, joints and fastenings between items of equipment and materials (gaskets and seals) must have extremely low gas permeability. Full-welded joints are recommended for all permanent fixtures. Gasketed joints may deteriorate in service, and this imposes continuing costs for periodic testing and repair.

Low-leak systems require quality construction for all components including boxes, filters, and associated ducts. Any inleakage associated with the filter mounting or connecting duct will adversely affect the quality of the inert atmosphere that can be maintained in the box and therefore the cost of inert gas purification. Penetrations must be minimized in both number and size. The use of smaller HEPA filters allows smaller ports for maintenance. Filter changes should be planned for times when other maintenance operations (routine or special) are taking place inside the box to reduce interruptions to operations, to reduce the loss of inert gas, and to minimize the time required to recondition box spaces.

For fire protection, the preventive step of inerting is more satisfactory, though more expensive, than extinguishing a fire if it does occur. However, oxygen must be reduced below 1% before it fails to support the burning of some pyrophoric metal.[9] The use of dry air (relative humidity less than 20%) reduces the hazard of pyrophoric metal fires but does not eliminate it. Moisture in the presence of heated pyrophoric or reactive metals, such as finely divided plutonium, increases the possibility of explosion by generating hydrogen. The suitability and cost of an inert gas for the process are significant factors when selecting this type of fire control. The gas flow rate in most inert gas boxes is kept as low as possible to be consistent with required box-atmosphere purity levels; low-capacity filters are frequently used. The

inert gas may be purged on a once-through basis or recirculated through a purification unit. A word of caution concerning commercially available (off-the-shelf) recirculating glove boxes: at one ERDA installation, over half of the problems with glove boxes during the last five years involved this type of installation, even though commercial boxes represented less than one-tenth of the boxes on hand. Some problems were caused by vacuum-pump oil-mist plugging of a HEPA filter, others by the failure of vacuum relief solenoids. Factory Mutual Research Corporation published a report on oil mists from vacuum pumps.[24] The statistics point up again that off-the-shelf items cannot be used in a containment-type ventilation system without evaluation, nor can they be applied as "black boxes" by those responsible for operational safety.

7.5.3 Control and Instrumentation

Glove box instrumentation may range from simple indicators and alarms to sophisticated control systems. The type of control or instrument used will depend on the characteristic to be monitored, the relative hazard, and the method and time available to correct an upset condition. Operational characteristics to be measured should always include the differential pressure between box and surroundings, the filter resistance, the gas flow rate through the box, and the box atmospheric temperature. In addition to instruments on the box, it may be necessary to indicate and provide for readout and/or alarm at a central panel for oxygen content, liquid level, neutron flux, gamma flux, fire, or explosive gas mixture inside the box.

When, for safety, a monitored characteristic requires annunciation when the level of a monitored parameter passes some predetermined point (e.g., an alarm when the glove box pressure differential becomes less negative than 0.3 in.wg relative to the surroundings), the alarm may be local, that is, alerting the operator to the upset condition, or it may signal an annuciator panel in an adjoining "cold" area by the entry door to the glove box room or in a control room, or both. There should be a written procedure in addition to sufficient information on the current contents of each box to allow evaluation of the hazard when an alarm sounds and to plan corrective action.

The minimum instrumentation for a glove box ventilation system should include devices to indicate the differential pressure between the box and its surroundings, and to indicate filter resistance, total exhaust flow rate, and exhaust air temperature. Figure 7.22 shows the arrangement of indicating devices in a glove box ventilation system. The items shown above the double-dashed line (Fig. 7.22) indicate the types of instruments commonly used to supplement the minimum instrumentation necessary to improve safety for a particular operation or circumstance. For example, when box operators are not in full-time attendance for a continuous process, a sensor can be provided to monitor abnormal pressure or temperature and to actuate an alarm at a remote point where an attendant is stationed.

Figure 7.23 shows a typical local mounting for an aneroid differential pressure gage on top of a glove box. The instrument should be mounted near eye level, and the indicating face should always be located so that the operator has a clear view while manipulating the gloves. Sensing lines should be short and sloped directly back to the box so that moisture will not pocket in the tube. Tubing should be at least $^3/_{16}$ in. ID to allow the instrument to respond quickly to rapid changes in pressure. Use of a three-way vent valve at the gage permits easy calibration (zeroing) without disconnecting the sensing tube. Calibration of glove box differential pressure gages should be a weekly routine.

Most users prefer an instrument pressure range of 0 to 1 in.wg; however, the instrument must have a proof pressure greater than the maximum system pressure (negative or positive) so that it will not become inoperable or leak during a system pressure transient. Liquid-filled devices are not recommended for glove box pressure indicators, because liquids can be sucked into the box or filter if the safety traps on the manometer leak, as they often do after long exposure to high pressure. The aneroid gage has a diaphragm that seals the path against contamination leakage.

Inlet air filters on air-ventilated glove boxes do not require differential pressure gages. The pressure drop across the filter is approximately the differential pressure across the box pressure boundary. Inlet flow rates can be measured periodically and with acceptable accuracy (±15%) with a portable instrument, such as a thermal anemometer (see Chap. 9, *Industrial Ventilation*).[25] When inlet filters become clogged enough to limit the inlet flow below the volume needed to serve the box, they must be changed.
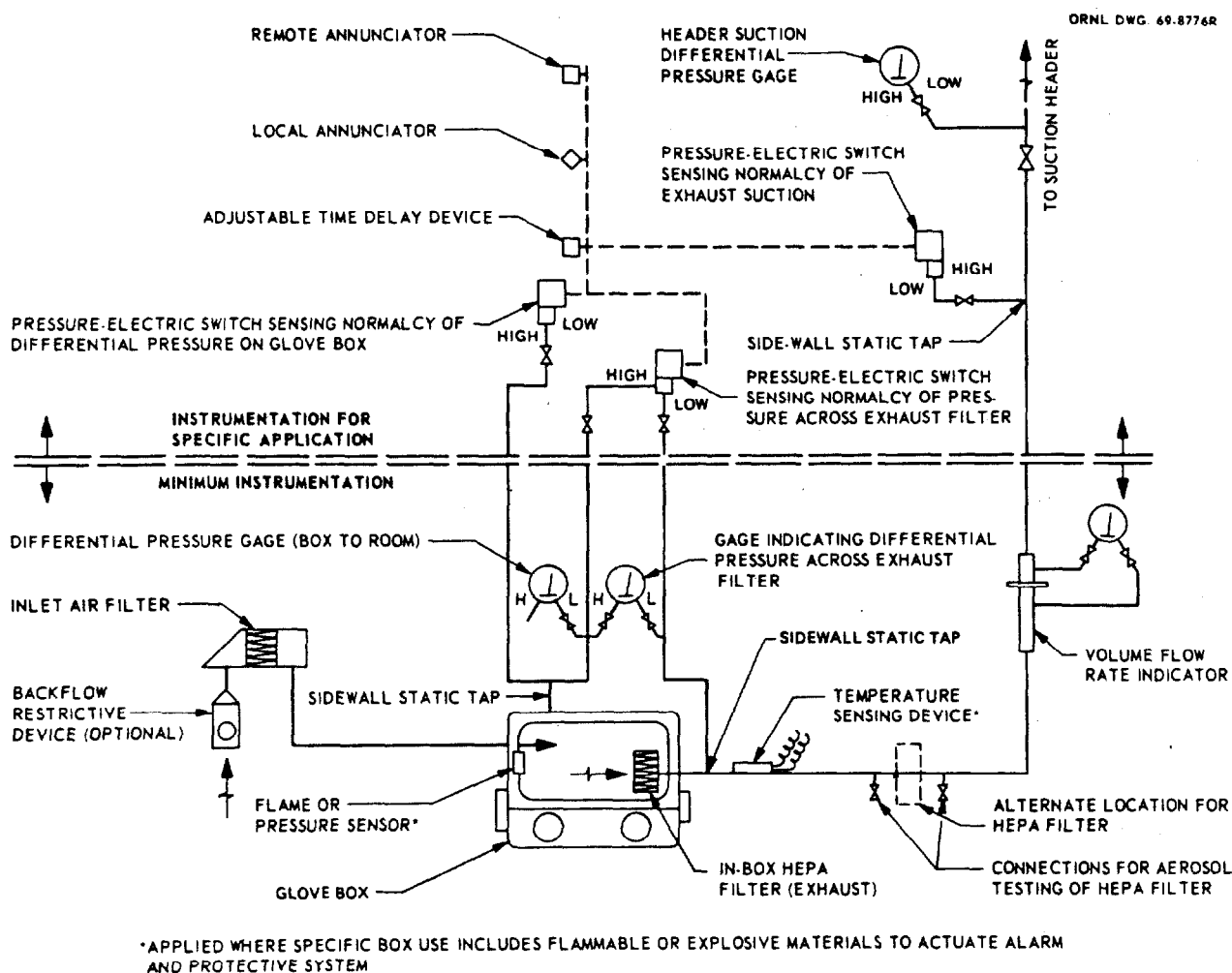
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Fig. 7.22. Instruments in a glove box ventilation system.

*APPLIED WHERE SPECIFIC BOX USE INCLUDES FLAMMABLE OR EXPLOSIVE MATERIALS TO ACTUATE ALARM AND PROTECTIVE SYSTEM
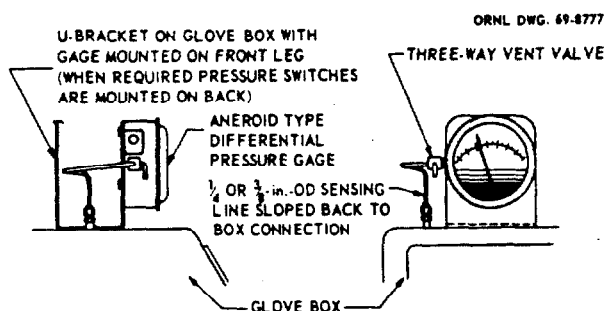
ORNL DWG. 69-8777

Fig. 7.23. Aneroid gage to indicate differential pressure between the glove box and the laboratory.

A differential pressure gage should be provided for each exhaust HEPA-filter stage to indicate filter resistance. Pressure-sensing connections can be provided to permit the use of portable instruments. As Fig. 7.22 shows, a dual (high-low) pressure switch

can be used to actuate an alarm when a predetermined resistance limit is exceeded or a loss of suction is experienced. Suitable alarms or controls that can function on small pressure differentials (≤ 0.25 in.wg) are difficult to keep in proper calibration and are often expensive. Figure 7.24 shows a method of indicating pressure drop through a filter. Section 5.6 gives further information on differential pressure instrumentation.

Instruments used to measure airflow rates from glove boxes include an orifice plate, venturi meter, flow nozzle, and calibrated pitot tube. The important point is to use a simple, trouble-free device that gives reliable readings within $\pm 15\%$ accuracy. When free moisture is absent, a pitot tube is the least expensive and most adaptable device for the small volume flow rates associated with glove box ventilation. Velocity pressure measurements (corrected for pitot-tube

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single centerline location[26]) for air flows and duct sizes common in glove box applications are given in Fig. 7.25. The corrections shown are for air at 60°F and 14.7 psia and neglect the pitot-tube coefficient. Pitot tubes are available with coefficients of 1.00, but there is an advantage in using the more common commercial pitot tube with a coefficient of 0.825 at low flow velocities. The equation for measuring velocity with a pitot tube is

$$V = K (2gh)^{1/2} ,$$ (7.5)

where

$V =$ fluid velocity, ft/sec;
$K =$ coefficient of the pitot tube;
$g =$ acceleration of gravity, 32.17 ft/sec^2;
$h =$ velocity pressure (ft) of the air–gas stream.

The following equation is used for air at standard conditions:

$$V = 4005 \, K \, (h_w)^{1/2} ,$$ (7.6)

where

$V =$ fluid velocity, fpm;
$h_w =$ velocity pressure, in.wg.

A pitot tube with a coefficient of 0.825 has a velocity pressure reading that is 1.47 times the velocity pressure reading of the pitot tube with a coefficient of 1.00 for the same fluid velocity. This pressure differential allows the low velocities often encountered in glove box ventilation to be measured more easily.

Figure 7.26 shows the arrangement of a round orifice in a straight section of metal duct. Either method (pitot tube or orifice) can be used to read the flow volume directly on a properly calibrated gage. For a thin square-edge round concentric orifice with the properties given in Fig. 7.27, flow rate can be determined, with sufficient accuracy for glove box applications, by the following equation:

$$Q = 14d^2h^{1/2} ,$$ (7.7)

where

$Q =$ airflow, cfm;
$d =$ orifice diameter, in.;
$h =$ pressure drop across orifice, in.wg.

Assumptions inherent in the constant 14 used in Eq. (7.7) are (1) air at standard temperature and

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Fig. 7.24. Method of indicating pressure drop across a filter. Liquid-filled manometer is not recommended for this service.
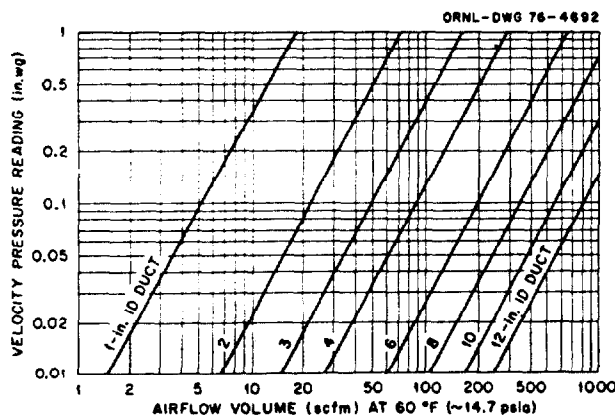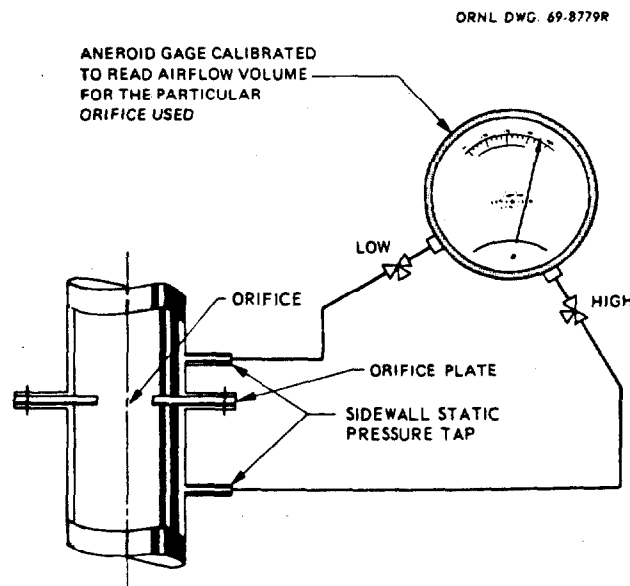

Fig. 7.25. Single centerline pitot-tube corrected airflow volume measurements.

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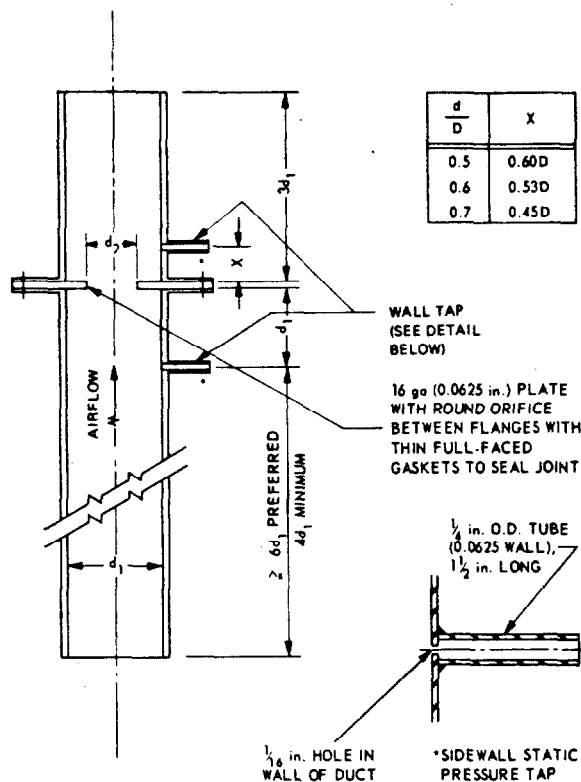Fig. 7.26. Orifice meter method of measuring volume flow rate in small ducts.

Fig. 7.27. Arrangement of thin, sharp-edge concentric orifice in small duct.

pressure, (2) flow coefficient for orifice = 0.65, and (3) ratio of orifice diameter to smooth-duct diameter, D, = $0.2 \leqslant d/D \leqslant 0.7$. The practical use of this formula can be shown by the following example.

Determine the orifice size necessary for a 20-cfm airflow rate that would give a reading near the center of scale on a 0- to 0.50-in.-range gage.

$$Q = 20 \text{ cfm}$$

$$h = \frac{0.50}{2} = 0.25 \text{ in.wg}$$

$$d = \frac{Q}{14h^{1/2}} = \frac{20}{14(0.25)^{1/2}}$$

$$d = 1.79 \text{ in.}$$

For 3-in. sched 10 stainless steel pipe (ID = 3.260 in.), the d/D ratio is $1.79/3.26 = 0.55$, which is within the acceptable range.

A shortcoming of the thin-plate orifice is the loss of head of the air flowing through the device. The

following tabulation gives the loss of head of concentric orifices for various d/D ratios:

d/D ratio	Fraction of velocity head not regained
0.2	0.95
0.3	0.89
0.4	0.83
0.5	0.74
0.7	0.53

In the example above, $0.70 \times 0.20 = 0.14$ in.wg. is the pressure loss when 20 cfm flows through the orifice of $d/D = 0.55$.

Immediately after installation, while filters are still clean, the measured pressure drop across the HEPA filter can be used to check airflow to a good degree of accuracy by proportioning the measured pressure drop to that stamped on the filter case at the time of predelivery testing. The pressure drop across the filter is no longer a dependable indication of gas flow rate after the filter has accumulated dust. After a filter has been in service for a period of time, it is necessary to measure both the pressure drop across the filter and the airflow through it to evaluate the filter's status and relationship to the whole ventilation system.

Written procedures for periodically testing each alarm, control, and emergency system serving the glove box and its ventilation system are essential.

7.5.4 DOP Testing of Glove Box Filters

HEPA filters must be tested immediately after installation and then periodically to assure that air cleanup capability and containment integrity remain intact. The principles of DOP testing of HEPA filters are given in Chap. 8. The HEPA filters used in glove box systems are often inconvenient to test because DOP must be injected into the inlet duct or glove box. Figure 7.28 shows the usual methods for injecting DOP and extracting samples for glove boxes. DOP cannot be fed into the inlet of the box to test the exhaust-side filters if high-efficiency filters are used in the inlet. Methods A and B (Fig. 7.28) require that DOP be drawn into the glove box by the suction of the exhaust system. However, when glove boxes house apparatus with open or exposed optical lenses and with highly polished surfaces, delicate balances, crystalline structures, sensitive conductors, or similar equipment or products, DOP should not be injected into the box. In such cases, the filter should be installed in the duct downstream of the glove box so that the injected DOP aerosol will not back up into
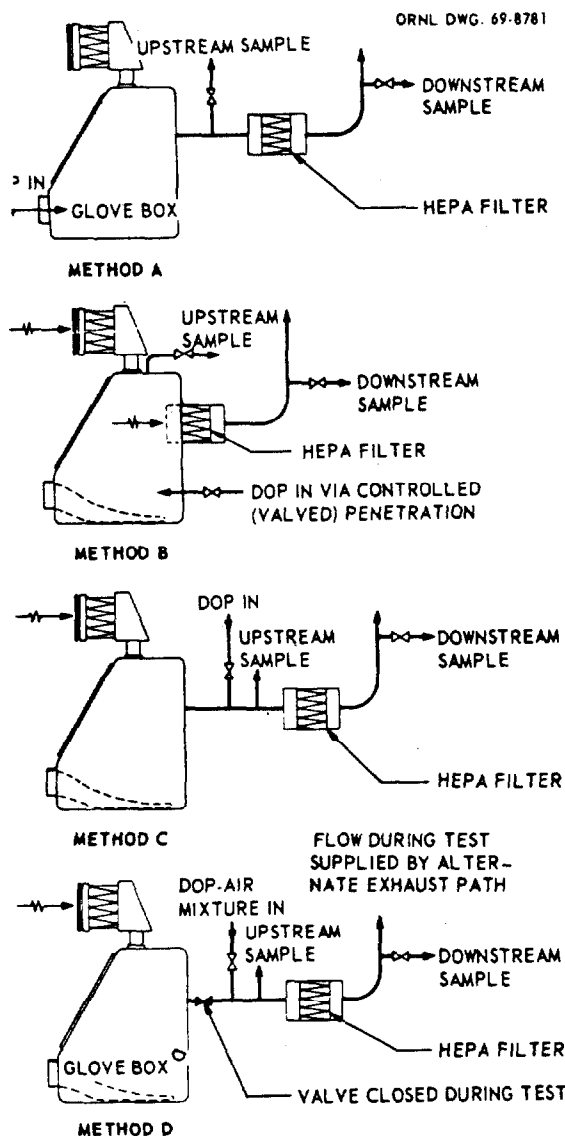
Fig. 7.28. Four methods of DOP testing HEPA filters in glove-box exhaust streams.

Fig. 7.29. Connection for introducing DOP into glove box.

the glove box proper. Method C (Fig. 7.28) may then be used for DOP testing the exhaust HEPA filter.

Where new or replacement exhaust filters are required to be tested before restarting the ventilation system, method D may be used. Note in this method that the exhaust path from the glove box is closed and that the DOP—air mixture for filter testing is drawn from a separate valved path. The side path is closed and sealed after testing is completed.

Methods A and B (Fig. 7.28) require DOP—air mixtures to be injected into the glove box via some convenient opening. A glove port can be used if
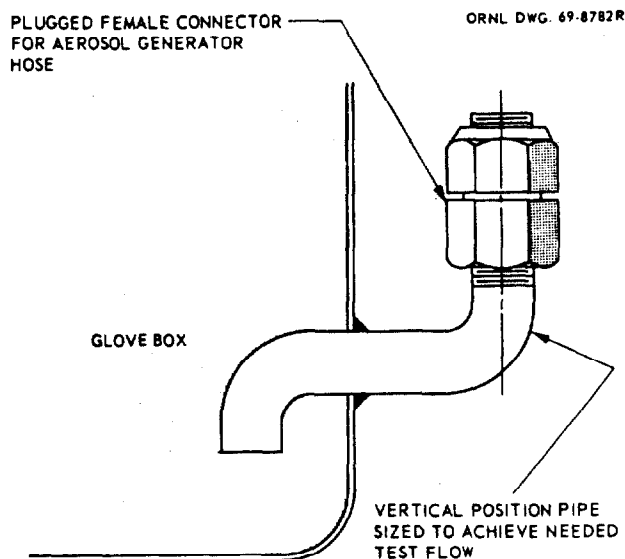
containment is not critical during testing. Otherwise, a connection can be prepared (Fig. 7.29) or an alternate method can be devised. Methods C and D (Fig. 7.28) do not require the introduction of DOP into the glove box. The DOP inlet connection must be sized to pass the DOP or DOP—air mixture. The connection for concentrated DOP in method C must admit 2 to 5 cfm, while the connection in method D must accommodate the total DOP—air mixture used for the test.

7.5.5 Glove Box Shielding

Some glove boxes may require gamma or neutron shielding because of the nuclide used and the amount of material involved. Boxes handling kilogram quantities of plutonium can be shielded by providing lead-impregnated gloves and by installing lead sheets over the metal portion, lead glass over the windows, and lead-hinged covers over the ports.[27] The operating, shielding, removal, and replacement requirements of the glove box HEPA filter must also be considered when glove box shielding is required.

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